

State of dispatcher systems in Bulgaria and their role in the liberalised passenger rail market

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ABSTRACT

Modern dispatcher systems are a key element of railway traffic management, directly shaping punctuality, operational reliability, and passenger comfort. In a liberalised passenger rail market, where operators compete through service quality, punctuality becomes a critical determinant of competitiveness. This paper examines the current state of dispatcher systems in Bulgaria, identifying technological disparities and their impact on operations. A conceptual framework is developed to show how automation, communication quality, and safety systems influence punctuality and, consequently, perceived comfort. A comparative analysis of the Sofia-Plovdiv and Sofia-Burgas corridors illustrates how different modernisation levels affect performance. The results show that completing dispatcher system upgrades significantly improves punctuality, reduces delay propagation, and enhances service predictability. These improvements directly increase passenger comfort and strengthen operator competitiveness in an open market. The findings demonstrate that dispatcher system modernisation is not only a technical requirement but a strategic prerequisite for equal access, higher service quality, and successful liberalisation of passenger rail transport in Bulgaria.

KEYWORDS

Dispatcher systems, Punctuality, Passenger comfort, Railway operations, Liberalised rail market

1. INTRODUCTION

The liberalisation of the European passenger rail market, driven by the Fourth Railway Package (Directive 2016/2370/EU) [1], imposes stringent requirements on the quality and reliability of railway operations. Infrastructure managers are obliged to provide transparent, non-discriminatory access to all licensed operators. At the same time, service quality-measured above all by punctuality-becomes the primary competitive differentiator in an open market. Dispatcher systems occupy the pivotal position in this chain: they are the operational backbone through which traffic control decisions are made, real-time communication is sustained, and safety is enforced. Their technological state, therefore, largely determines whether the conditions for meaningful liberalisation can be met.

Bulgaria has already taken a concrete step beyond the regulatory framework: the country has liberalised its passenger rail market both de jure and de facto. A private passenger rail operator has been formally awarded the right to provide services alongside the state incumbent on domestic routes, making Bulgaria one of the few countries in Southeast Europe where effective passenger-rail competition is set to become an operational reality rather than a future regulatory objective. Although this competition will take place primarily within the framework of Public Service Obligation (PSO) contracts rather than pure open-access operations, the practical outcome remains the same: two operators will share the same infrastructure and will compete on service quality, punctuality, and passenger experience.

In February 2026, 12-year PSO contracts were signed under Regulation (EC) 1370/2007 [2]: the Western Region (~75% of train-km) was awarded to BDZh - Passenger Services, while the Northern and Southern Regions (~25% combined) were awarded to the private operator Ivkoni Express EAD, at rates of 8.99/7.63/7.84 EUR per train-km respectively [3]. Total public support over the 12 years amounts to EUR 1.8 billion for BDZh and EUR 511 million for Ivkoni Express [3]. These contracts will enter into force on 13 December 2026, and their signature constituted an explicit conditionality for Bulgaria's access to EUR 734 million in EU Recovery and Resilience Facility funding for 35 new trainsets [4].

With a new operator fully dependent on shared infrastructure once the contracts become operational, the technological state of dispatcher systems becomes a matter of direct contractual and operational urgency. The ability of the private operator to deliver competitive levels of punctuality and comfort will depend entirely on the infrastructure it does not control and must share with the incumbent, making dispatcher system performance a central determinant of the sustainability of the liberalised market that is about to emerge.

In Bulgaria, the National Railway Infrastructure Company (NRIC) manages the railway network, within which significantly different generations of signalling and interlocking installations coexist across individual stations. Modern technologies such as Centralised Traffic Control (CTC), GSM-R digital radio, and ETCS have been implemented mainly along key sections of the core TEN-T network. The most advanced deployment is along Railway Line No. 1 (Sofia-Plovdiv-Svilengrad), classified as a railway main line under the national line categorisation framework [5]: the southern section Krumovo-Svilengrad operates entirely under the Elektra-2 dispatching system, while the Sofia-Plovdiv section is undergoing full reconstruction [6].

The older analogue platforms - Dispatcher Communication System (DPS) and Unified Telegraph Communication (ETK) - remain in operation across a substantial part of the network. A study on the development of transport infrastructure in Bulgaria and the region, conducted by Dimitrov and Petrova [7], traces this uneven modernisation and shows that investments are concentrated primarily along international corridors, while large portions of the network remain only minimally upgraded.

According to the 2024-2025 Network Statement of SE NRIC [8], the total developed length of the managed network reached 6,446 km (total developed length, including all tracks and sidings; route length: 4,025 km) as of 31 December 2023, of which 3,904 km are open line with standard gauge (1,435 mm). The network comprises 294 stations, 16 block posts, 397 halts, 186 tunnels, and 995 bridges, with more than 70% electrified using a 25 kV / 50 Hz AC overhead system.

Train control is carried out through key relay-based systems (KIRS), semi-automatic and automatic block systems, and - on certain sections - centralised dispatching control. The TPMS system is deployed network-wide for real-time train monitoring and timetable management, while ARAMIS provides centralised control of the Krumovo-Dimitrograd-Svilengrad section from the Dispatching Centre in Plovdiv [8].

Station-level safety equipment includes KIRS, MRC, and MKC interlocking installations. Centralised control from a unified supervisory centre is available only on the sections Iliyantsi-Karlovo (Line 3, TRIS CTC) and Septemvri-Svilengrad (Line 1, Elektra-2/ARAMIS). Double-track sections total 995 km, while the narrow-gauge line Septemvri-Dobrinishte (760 mm) extends over 125 km [8].

This territorial asymmetry in infrastructure investment forms the structural context within which differences in dispatching systems must be understood. The technological heterogeneity has direct and measurable consequences for punctuality, delay propagation, and post-incident recovery. Previous research has identified the dispatching-system infrastructure as a major source of operational unreliability in the Bulgarian railway context, particularly on lines where outdated equipment remains in service [9]. The incident-risk profile is closely linked to the adequacy of maintenance, the condition of dispatching systems, and the quality of communication links [9].

The dispatcher function itself is among the most complex and cognitively demanding roles in railway operations. Modelling the work of train dispatchers has been a research concern since the early era of computerised railway management [10]. As network complexity has grown and traffic density has increased, the adequacy of dispatcher training and qualification has become an increasingly pressing issue [11]. Both the cognitive demands placed on dispatchers and the technical systems they operate have evolved substantially, culminating in the current generation of intelligent management systems that integrate real-time data, automated conflict detection, and decision-support interfaces [12], [13].

This paper analyses the current state of dispatcher systems in Bulgaria, examines their impact on operational performance across selected corridors, and discusses the implications for the liberalised passenger rail market. The structure is as follows: Section 2 reviews the European context and the relevant literature; Section 3 describes the principal technology layers of Bulgarian dispatcher systems and their deployment status; Section 4 discusses the relationship between dispatcher modernisation, punctuality, and passenger comfort; Section 5 presents a comparative corridor analysis; and Section 6 draws conclusions for infrastructure policy and liberalisation strategy.

2. LITERATURE REVIEW AND EUROPEAN CONTEXT

European experience consistently shows that the technological state of traffic management systems is a prerequisite for both high operational quality and effective rail market liberalisation. Countries that have completed or substantially advanced the deployment of ETCS, GSM-R, and CTC have recorded measurable reductions in train delays, more stable adherence to schedules, and higher passenger satisfaction. These outcomes, in turn, create the operational conditions under which open-access competition can deliver genuine consumer benefits rather than simply redistributing passengers between unreliable services. A structured study of railway passenger transport across the European Union by Stoilova et al. [14] provides empirical context for these trends, documenting the wide variation in punctuality performance and service quality across member states and identifying infrastructure modernisation as the most consistent differentiator between high- and low-performing national networks. A multi-criteria evaluation of the TEN-T Orient-East Med Corridor

by Stoilova et al. [15] confirms that network-level performance gaps in Bulgaria reflect infrastructure capability deficits of precisely the kind examined here.

Within the Bulgarian context, a foundational quantitative picture is provided by Karagyozev and Todorova [16], who conducted a systematic analysis of delays affecting both freight and passenger trains across the Bulgarian railway network. Their work identified infrastructure condition and communication system limitations as primary contributors to the accumulation of delays, findings that remain relevant as the modernisation programme proceeds unevenly. The risk dimension of passenger train delays has been further examined by Stoilova [17], whose risk analysis of delay patterns in the rail network links delay probability distributions to infrastructure and operational characteristics at the line level. This probabilistic perspective complements the delay-causation analysis in [16] and provides an additional analytical tool for quantifying the operational impact of gaps in the dispatcher system. The propagation of delays through the network has been further studied using GERT-based network modelling: Todorova [18] developed a GERT model of a technical station that quantifies passenger trainset delays as a function of station operations and their stochastic variability. This approach demonstrates that delay generation at individual operational nodes—precisely the nodes where dispatcher capability is most consequential—can be modelled and predicted with sufficient precision to support investment planning.

Simulation modelling of railway sections provides a complementary tool for evaluating the impact of infrastructure and control system parameters on operational performance. Atanasov and Todorova [19] developed a simulation model of a railway section that captures the interaction between timetable structure, infrastructure characteristics, and operational disturbances. Such models are directly applicable to assessing before-and-after scenarios for dispatcher system upgrades, providing an analytical foundation for evidence-based modernisation decisions.

Passenger comfort research quantifies the commercial stakes: Todorova and Trifonov [20] establish through Fuzzy-AHP that time-related attributes carry the highest weight in passenger assessments, while Todorova's Logit-based mode choice model [21] shows that punctuality improvements translate directly into modal shift and operator revenue.

The digitisation dimension of railway management has been examined in the broader context of workforce challenges and system design. Todorova [22] analysed the implications of digitisation in railway transport for workforce structure and competency requirements, identifying the transition to digital dispatcher systems as one of the most significant sources of skill disruption in the sector. The methodological basis for intelligent railway management systems has been laid out by Dimitrov et al. [12], who articulated the goals, tasks, and architectural logic of intelligent rail management platforms, and extended this analysis to include the methodological and technical aspects of digital transport management models [23]. A comprehensive overview of problems and solutions in intelligent transport management was provided by Dimitrov, situating the challenge of dispatcher system modernisation within the broader transition toward AI-assisted and data-driven traffic control.

Real-time management systems for railway nodes have been studied in the context of marshalling yards by Dimitrov et al. [24], who proposed a methodological approach to developing real-time yard management systems, and by Tomov et al. [25], who optimised the wagon sorting process within such systems. While focused on freight operations, the system architecture and real-time data integration principles developed in this line of research are directly transferable to passenger dispatcher system design. Station-level operational optimisation has been addressed specifically for passenger complexes by Todorova [26], whose analysis of shunting process optimisation at a passenger complex illustrates the operational efficiency gains achievable through systematic management improvement at the node level.

Finally, the infrastructure-charging dimension of liberalisation—central to ensuring equitable access—has been examined by Todorova [27], who analysed infrastructure charges in the new EU member states and identified the tension between cost-recovery requirements and the need to attract new operators. Unequal infrastructure capabilities—including disparities in dispatcher systems—compound this tension by creating differential operating conditions that no pricing mechanism can fully compensate for.

3. DISPATCHER SYSTEMS IN BULGARIA: ARCHITECTURE AND STATUS

3.1. Railway Line Numbering and Categorisation

Under the Ordinance on the Categorisation of Railway Lines in the Republic of Bulgaria (Council of Ministers Decree No. 293/2001, last amended 2022) [5], the national railway network is divided into four categories: railway magistral (equivalent to European-corridor main lines), Category I lines (international connections and magistral feeders), Category II lines (regional lines), and Category III lines (private/industrial sidings). The three lines examined in this paper span the two highest categories and are numbered as follows in Annex 4 of the Ordinance.

Railway Line No. 1 (railway magistral) runs from Kalotina-West (state border with Serbia) through Sofia - Plovdiv - Dimitrograd to Svilengrad (state borders with Greece and Turkey). This corridor forms the Bulgarian section of the Orient/East-Med TEN-T Core Network corridor and is classified entirely as a railway magistral under Annex 1 of the Ordinance. It is the principal Sofia-Plovdiv axis examined in this paper. The stations along the line, from Sofia to Svilengrad, include: Sofia (София) - Elin Pelin (Елин Пелин) - Kostenets (Костенец) - Septemvri (Септември) - Pazardzhik (Пазарджик) - Plovdiv (Пловдив) - Krumovo (Крумово) - Dimitrograd (Димитровград) - Harmanli (Харманли) - Svilengrad (Свиленград).

Railway Line No. 3 (Category I) runs from Iliyantsi (Илиянци) - Karlovo (Карлово) - Tulovo (Тулово) - Dabovo (Дъбово) - Zimnitsa (Зимница), and Karnobat (Карнобат) - Komunari (Комунари) - Sindel (Синдел) - Varna Ferry (Варна фериботна). This line provides the direct Sofia-Burgas connection via an inland route and is classified as Category I in Annex 2 of the Ordinance (section Iliyantsi-Karlovo-Tulovo). The 138 km section from Iliyantsi (Sofia area) to Karlovo is equipped with the TRIS CTC system managed by the Sofia Dispatcher Centre. Key stations along the Sofia-Burgas axis of Line No. 3 include: Iliyantsi (Илиянци) - Kurilo (Курило) - Bunovo (Буново) - Anton (Антон) - Karlovo (Карлово) - Tulovo (Тулово) - Stara Zagora (Стара Загора) - Zimnitsa (Зимница) - Karnobat (Карнобат) - Burgas (Бургас).

Railway Line No. 8 (railway magistrale) runs from Plovdiv (Пловдив) - Filipovo (Филипово) - Skutare (Скутапе), and Plovdiv Razpredelitelna-Iztok (Пловдив разпределителна-изток) - Stara Zagora (Стара Загора) - Zimnitsa (Зимница) - Karnobat (Карнобат) - Burgas (Бургас). The Plovdiv-Burgas segment of Line No. 8 is classified as a railway magistrale under Annex 1 of the Ordinance. It is the primary axis for the Sofia-Burgas corridor considered in this paper, with trains running from Sofia via Line No. 1 to Plovdiv and continuing east on Line No. 8. The full route from Sofia to Burgas using this path covers approximately 402 km. This line is currently under modernisation by the INTERFLO CTC system (Alstom), with commissioning targeted for 2030.

Sofia and Burgas are served by two distinct routing options. The first is via Line No. 1 (Sofia-Plovdiv, magistrale) and Line No. 8 (Plovdiv-Burgas, magistrale), totalling approximately 402 km. The second is via Line No. 3 (Iliyantsi-Karlovo-Tulovo-Zimnitsa-Karnobat-Burgas), a Category I line, which offers a more direct inland route. Both routes share the Karnobat-Burgas final section. The existence of these two competing routes means that both infrastructure quality and dispatcher system capability on each corridor directly influence which route operators prefer and how reliably the Black Sea connection can be served, a factor of particular relevance under the 2026 PSO contracts [3].

3.2. Principal Technology Layers

Bulgarian dispatcher systems cover a wide technological spectrum, structured in a five-level hierarchy - from basic mechanical dependencies to fully digital route-computer interlocking. The hierarchy progresses as follows: (1) stations without any signalling equipment ("Bez OT"); (2) key-dependency arrangements, in which the interdependencies between points and signals are ensured through mechanical keys; (3) electromechanical systems (EMC) - a transitional generation between mechanical and relay-based interlockings; (4) route-relay systems (MRC), comprising several generations - the WSSB-1 and WSSB-2 families, the N-68 family in its three variants (basic, N-68U, N-68V, MN-70), as well as Block Route-Relay Centralisation (BMRC), considered the latest generation in this group, where a computer-based control and visualisation system is now added; (5) route-computer interlocking (MKC), which provides fully digital interlocking, compatible with CTC, with real-time visualisation and centralised route control.

Route-relay systems automate route setting but do not support full CTC functionality at network level. Above them are modern digital interlocking platforms such as Elektra-2 and TRIS, which enable full CTC integration and centralised supervision. At an even higher conceptual level stand integrated automation environments of the INTERFLO type, combining CTC, train-graph visualisation, and operational data exchange between multiple operators.

The key operational threshold is the continuous deployment of MKC along the entire corridor section. Only once full coverage is achieved can the dispatcher control the entire section from a single workstation, without relying on local staff to execute interdependent commands.

3.3. Deployed Dispatcher Centres: Characteristics and Capabilities

Bulgaria operates two fully commissioned centralised dispatcher centres and has a third under deployment (2030). The Plovdiv Dispatcher Centre runs the Elektra-2 CTC system on the Krumovo-Svilengrad section of Railway Line No. 1 (Orient/East-Med TEN-T magistrale) [5]. Built on a SIL 4-certified, triple-redundant platform and transmitting all commands via optical fibre, Elektra-2 is fully centralised on this section; the Sofia-Plovdiv section is undergoing comprehensive reconstruction with ETCS Level 2 and GSM-R [6], [28]. The Sofia Dispatcher Centre runs TRIS CTC on the 138 km Iliyantsi/Kurilo-Karlovo section of Line 3, with Automatic Route Setting (ARS), event logging, and full ERTMS compatibility; the remainder of Line 3 operates under conventional supervision. INTERFLO, developed by Alstom for the full Plovdiv-Burgas axis (Line 8, magistrale), will integrate automated train control, axle-count block working, and dual-redundant signalling networks upon commissioning. The legacy N-68 relay-based systems, whose residual certified life expires around 2032 [29], lack automated conflict detection and rely on manual telephone coordination, causing delays to propagate unchecked on mixed-technology corridors-the highest-risk operational phase [30]. The Network Statement 2024-2025 confirms that SE NRIC also operates the ARAMIS Dispatching Management System on the Krumovo-Dimitrovgrad-Svilengrad section, enabling control from a single centre while simultaneously serving passenger information boards at stations along the route. Safety equipment (signalling) at the station level relies on KIRS interlocking or station interlocking systems combined with semi-automatic or automatic block-working between stations. Where stations are undergoing reconstruction, temporary control panels (PVU) are deployed in lieu of full interlocking, introducing transient automation gaps during transition periods. For trains not equipped with on-board ETCS hardware, operation on ETCS-equipped lines is permitted at a maximum speed of 130 km/h, preserving throughput but limiting the full benefit of train-protection automation.

3.4. Comparative Analysis: Route-Relay Interlocking vs Route-Computer Interlocking (MKC)

The principal operational distinction in Bulgaria lies between legacy route-relay interlocking (RRI, type N-68), which relies on verbal authorisation and manual route execution, and modern route-computer interlocking (MKC), which performs automated safety checks and accepts commands directly from the CTC workstation. In practice, RRI operation introduces several minutes of human-mediated delay per movement, whereas MKC enables sub-minute execution with automatic conflict detection preventing incompatible route allocations.

These two interlocking families underpin the three system layers that determine corridor-level performance. The CTC supervisory layer governs conflict resolution and traffic regulation, with markedly shorter decision cycles under full CTC operation compared to legacy supervision. The GSM-R communication layer, deployed in accordance with TSI CCS and ERA specifications, replaces the analogue DPS/ETK platforms [10], [11], [31], [32] and provides the digital bearer for ETCS. The ETCS train-protection layer, defined by TSI CCS [33], ranges from Level 1 (partial overlay using lineside signals) to Level 2 (continuous radio-based supervision without reliance on lineside signalling). The deployment status of these three layers across the network is summarised in Table 1.

ETCS Level 1 provides a safety overlay via Eurobalises alongside existing lineside signals, while Level 2 transmits movement authorities via GSM-R directly to the cab, eliminating lineside signals and enabling higher capacity. Bulgaria's current deployments operate on Baseline 2 (SRS 2.3.0d); migration to current baselines (B3R2/B4) will be addressed in the forthcoming upgrade cycle [34].

3.5. Deployment Status and Identified Gaps

Table 1 maps deployment status across the three principal corridors. The data reveal a pronounced asymmetry: Line No. 1 (TEN-T magistrale) is substantially modernised, whereas the Sofia-Burgas and Plovdiv-Burgas corridors retain legacy infrastructure and lack active EU-funded modernisation programmes.

Table 1: Dispatcher technology deployment status: Sofia-Plovdiv and Sofia-Burgas corridors; target values apply to the Sofia-Burgas corridor (INTERFLO project, completion 2030)

Indicator	Line 1: Sofia-Plovdiv-Svilengrad (magistrale, TEN-T)	Line 3: Iliyantsi-Karlovo (Cat. I)	Line 8: Plovdiv-Burgas (magistrale)	Line 8 Target (INTERFLO, 2030)
Dispatcher system	Elektra-2 CTC (Plovdiv DC) Krumovo-Svilengrad: active Sofia-Plovdiv: active reconstruction (incl. Elin Pelin-Kostenets: Transport Connectivity Programme)	TRIS CTC (Sofia DC) Iliyantsi-Karlovo: fully operational Karlovo-Varna: station interlocking (KIRS/MRC/MKC), telephonic dispatcher orders - no unified CTC centre	Legacy RRI N-68 (telephony-based) Sofia-Plovdiv section: see Line 1. Plovdiv-Burgas: INTERFLO modernisation in progress (Alstom, target 2030)	INTERFLO CTC (Plovdiv DC)
CTC coverage	100% (Krumovo-Svilengrad) Partial (Sofia-Plovdiv, under active reconstruction)	100% (138 km)	62% (partial)	100%
GSM-R / ETCS	94% / Level 2 (Krumovo-Svilengrad)	Deploying / Level 1	47% / Level 1 partial	100% FRMCS / Level 2
Legacy DPS/ETK	Decommissioned (active) Active (Sofia-Plovdiv reconstruction; new infrastructure upon completion)	Decommissioned	Active (53-61%)	Fully replaced
Mean delay / Punctuality	8.2 min / 78.4% (Krumovo-Svilengrad)	~78% (CTC section); improved punctuality following TRIS commissioning	18.6 min / 61.7%	Target: ≤8 min / ≥85%
EU funding	CEF active (Sofia-Plovdiv reconstr.)	National/partial EU	Rehabilitation of Plovdiv-Burgas railway line, Phase 2	CEF 2021-2027 (INTERFLO project)

NRIC operational reports for 2022-2024 [35] identify five systemic challenges: partial GSM-R coverage (fallback to analogue DPS/ETK); incomplete ETCS Level 1 deployment; automation discontinuities at technology boundaries; limited legacy-CTC interoperability; and, most consequentially, manual anomaly resolution, which raises average incident response time to 31 min on legacy segments versus 12 min under CTC-the primary driver of the punctuality gap documented in Table 1.

Beyond punctuality, Todorova and Filipov [9] document that legacy dispatcher infrastructure correlates with higher incident frequency and longer recovery times. Petrova [30] further identifies the mixed-technology coexistence period as the highest-risk phase, reinforcing the case for accelerated full-corridor modernisation.

Addressing these gaps is now the subject of an active pre-feasibility programme. SE NRIC is conducting pre-project studies for ERTMS deployment across five line sections (Administrative Contract No. DPTS-1/12.03.2024), co-financed

by the Cohesion Fund under the Transport Connectivity Programme with a total project value of BGN 6,240,084.51, executed over the period 12 March 2024 to 31 August 2026 [36]. The five sections under study are: Sofia-Mezdra-Gorna Oryahovitsa-Kaspichan-Sindel (existing line); Radomir-Kulata (existing line); Karnobat-Sindel (existing line under modernisation); Ruse-Gorna Oryahovitsa-Stara Zagora (existing line); and Vidin-Medkovets-Mezdra (line under modernisation). The studies are required to be aligned with the strategic deadlines of Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on TEN-T guidelines: core network by 2030, extended core network by 2040, and comprehensive network by 2050. For each section, three deployment scenarios for ERTMS Level 2 will be evaluated through legal, technical, economic and financial analysis, with risk and sensitivity assessment, environmental impact procedures, and detailed cost-benefit analysis prepared as the basis for subsequent procurement and construction [36].

4. DISPATCHER MODERNISATION, PUNCTUALITY AND PASSENGER COMFORT

4.1. The Modernisation-Punctuality Relationship

Dispatcher modernisation yields non-linear gains in punctuality, with the steepest improvements occurring during the transition from legacy to intermediate automation-the position of the Sofia-Burgas corridor today. GERT-based station modelling [18] and corridor-level simulation [19] provide quantitative frameworks for predicting these gains. Empirical evidence corroborates the pattern: Karagyozev and Todorova [16] document that delay accumulation is concentrated on segments with the weakest dispatcher infrastructure, consistent with Table 1. Beyond mean delay, intelligent management systems [12], [13], [23] reduce variance in operational performance-the dimension most damaging to passenger satisfaction and modal choice.

4.2. Punctuality and Passenger Comfort

Punctuality is the dominant comfort determinant in the Bulgarian context: Fuzzy-AHP analysis [20] assigns schedule adherence 22.9% of total comfort weight-ahead of vehicle hygiene (19.4%), intermodal connections (18.95%), and staff service level (15.6%)-establishing the dispatcher system as the infrastructure element most directly linked to passenger-perceived comfort.

The Logit mode-choice model [21] confirms that unreliable punctuality drives a systematic modal shift to car and coach, particularly among commuters and business travellers-so, in a liberalised market, a new operator's ability to attract passengers depends directly on the dispatching infrastructure it uses.

Real-time passenger information-a standard component of modern CTC platforms-partially offsets the impact of delays by reducing uncertainty and the perceived loss of control. Station-level optimisation, including improvements to shunting processes at passenger complexes [26], complements dispatcher-driven schedule adherence at the departure end of journeys.

4.3. Dispatcher Modernisation and Market Liberalisation

The Fourth Railway Package mandates non-discriminatory access to infrastructure. Yet, where dispatcher technology varies materially across corridors, operators face structurally unequal operating environments: punctuality levels achievable on a fully modernised corridor are physically unattainable on a legacy-equipped route, regardless of operator quality. Stoilova [37] documents this asymmetry for the Bulgarian context, identifying infrastructure quality differentials as a structural barrier to competitive market entry that regulatory pricing-or access-charge design calibrated for cost recovery rather than quality differentials [27]-alone cannot offset.

A further dimension concerns the equitable treatment of competing operators. Every conflict-resolution decision allocates delay between train operating companies; legacy manual dispatching lacks the formal optimisation frameworks to do so transparently, creating scope for discrimination favouring incumbent operators [38]. Modern CTC platforms with automated rescheduling incorporate formal fairness constraints [39], and their event logs (as in TRIS CTC and INTERFLO) provide verifiable records enabling post-hoc regulatory audits. Dispatcher modernisation thus serves a dual function: operational improvement and institutional infrastructure for equitable multi-operator access.

Workforce transition also requires structured management: Todorova [22] and Dimitrov and Petrova [40] favour corridor-by-corridor rollout, with Petrova and Trifonov [41] identifying an IPMA Agile-Waterfall approach as most effective for projects of this complexity [11].

The governance dimension of infrastructure management is equally significant for the success of liberalisation. Vasilev [42] identifies the effective management of public railway infrastructure as resting on three interdependent functions: access control, traffic management, and maintenance and development. Within the traffic management function, Vasilev specifically points to the deployment of ERTMS systems and modern information technologies as the primary lever for process improvement, while noting that key performance indicators (KPIs) for traffic management - including train kilometres, punctuality ratios, and track-occupation levels due to maintenance - must be monitored on a five-year horizon to support strategic governance. The same study identifies a structural weakness common to Balkan railway infrastructure managers: the absence of a modern cost-management system capable of attributing traffic-management costs at the level

of individual corridors or operational units [42]. In a multi-operator environment governed by PSO contracts, this deficiency directly impairs the transparent attribution of delay costs and infrastructure-use charges between competing operators - precisely the accountability requirement that the 2026 PSO contracts impose.

The 2026 PSO contracts add a contractual dimension to the dispatcher system's capabilities. With a single Line No. 3 service crossing two PSO lots (BDZh Western Region; Ivkoni Express Southern/Northern Regions), every dispatcher delay-allocation decision directly affects each operator's KPI performance and subsidy entitlement. Legacy N-68 segments, lacking automated event logging, cannot attribute delays between operators, as required by Regulation (EC) 1370/2007 [2]. Modern CTC platforms (TRIS CTC, INTERFLO) produce the operator-level performance records that the framework demands; legacy systems do not. Dispatcher modernisation is therefore a legal prerequisite for the equitable functioning of the new market structure.

4.4. Formal Model of Dispatcher System Performance

A compact formal model links three normalised indices-Automation Level A, Communication Quality C, Safety Integration S ($\in [0,1]$) - to two outputs: Punctuality Index P and Comfort Index K [43], [32], [39]. $P = w_1 \cdot A + w_2 \cdot C + w_3 \cdot S + \varepsilon$ (1) [$w_1=0.45, w_2=0.30, w_3=0.25$] $\delta = \delta_0 / (1+k \cdot A \cdot C)$ (2) [the A·C term captures that automation benefits require communication support] $K = \alpha \cdot P + \beta \cdot R + \gamma \cdot I$ (3) [$\alpha=0.50, \beta=0.35, \gamma=0.15$; R = reliability, I = information index] Results in Table 2.

Table 2: Model output: predicted punctuality, delay propagation, and passenger comfort by corridor and modernisation state

Indicator	Line 1 Sofia-Plovdiv-Svilengrad (magistrale, TEN-T)	Line 3 Sofia-Karlovo (TRIS CTC)	Line 8 Plovdiv-Burgas (legacy RRI/CTS)	Line 8 Target (INTERFLO, 2030)
Automation Level A	0.82	0.60	0.25	0.88
Communication Quality C	0.90	0.55	0.30	0.90
Safety Integration S	0.88	0.65	0.35	0.90
Predicted P - eq. (1)	$0.84 + \varepsilon$	$0.60 + \varepsilon$	$0.29 + \varepsilon$	$0.88 + \varepsilon$
Punctuality observed / target	78.4 %	~78%	61.7 %	≥85 %
Delay propagation δ - eq. (2)	0.64 (attenuates)	0.90	1.30 (amplifies)	≤0.65
Comfort Index K - eq. (3)	0.93	~0.79	0.70	≥90

Note: $\delta_0 = 1.5, k = 2.0$; $\varepsilon = 0.08$ (modernised main line), 0.19 (Cat. I line), 0.44 (legacy); R and I values: Line 1 0.95/0.85, Line 3 0.82/0.70, Line 8 legacy 0.78/0.40, Line 8 target 0.95/0.85.

Three findings emerge from Table 2. First, the delay propagation differential ($\delta = 0.64$ vs 1.30) confirms that a 10-min disruption attenuates to 6.4 min on modernised Line 1 but amplifies to 13 min on legacy Line 8 [43], [32]. Second, eq. (2) confirms automation gains require GSM-R support: automation alone yields $\delta \approx 0.99$ [31]. Third, the comfort gap ($K = 0.93$ vs 0.70) exceeds the raw punctuality gap by 7 pp, reflecting modernisation's multi-pathway effect on reliability and information provision [20].

5. CORRIDOR COMPARISON: SOFIA-PLOVDIV AND SOFIA-BURGAS

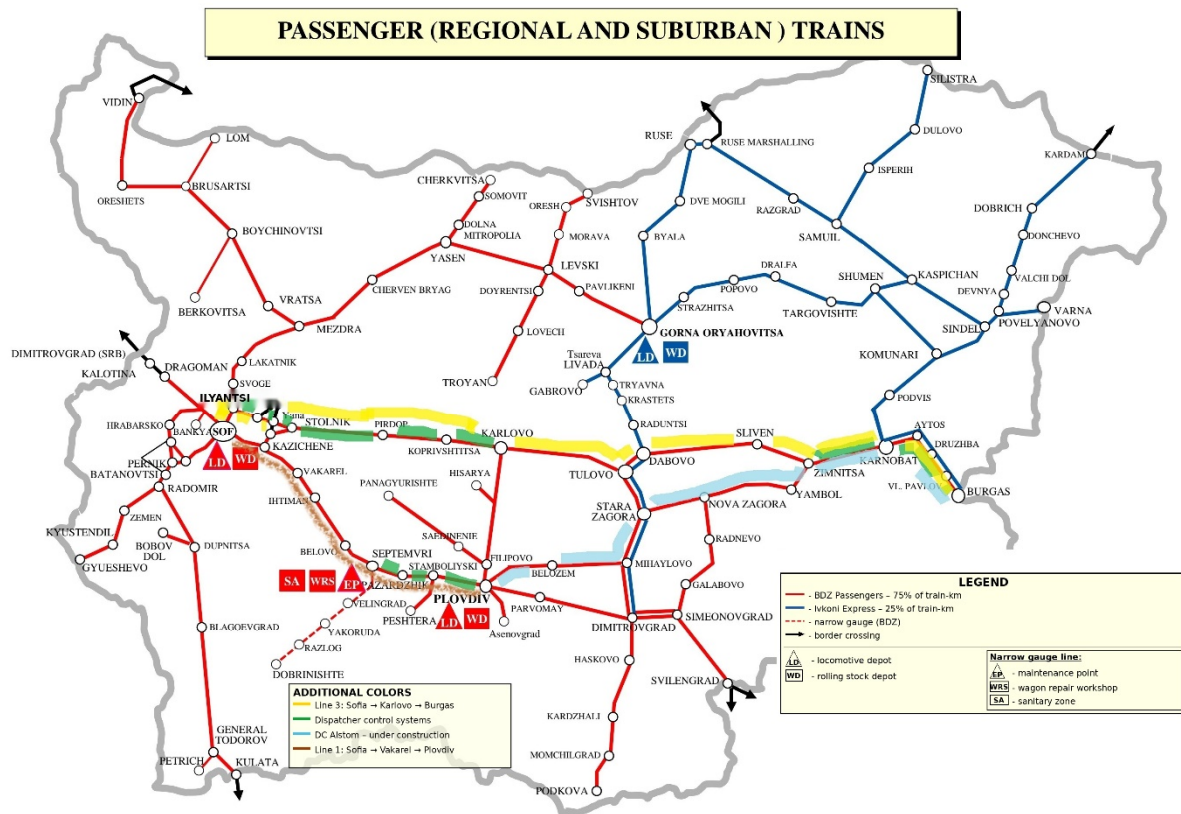


Figure 1: Passenger (regional and suburban) train network of Bulgaria: routes operated by BDŽ - Passenger Services (red) and Ivkoni Express (blue) under 12-year PSO contracts effective 13 December 2026. LD - locomotive depot; WD - rolling stock depot; EP - maintenance point; WRS - wagon repair workshop; SA - sanitary zone. Source: BDŽ-EAD network map, 2026.

5.1. Sofia-Plovdiv: Advanced Modernisation

The Sofia-Plovdiv corridor (153 km) forms part of the TEN-T Core Network and carries the highest passenger density on the Bulgarian railway network. The Septemvri-Svilengrad section is fully operational under the Elektra-2 CTC system, with 94% GSM-R coverage and ETCS Level 2 active. The Sofia-Septemvri subsection (incl. Elin Pelin-Kostenets) is under active reconstruction under the Transport Connectivity Programme; legacy DPS/ETK platforms are being progressively decommissioned. The corridor's mean delay of 8.2 min and punctuality rate of 78.4% (Table 1) reflect the best performance currently achieved on the Bulgarian network, constrained by the ongoing reconstruction phase.

The residual punctuality gap (vs the EU 80% benchmark) reflects factors beyond the dispatcher system: rolling stock reliability, dwell-time variability, and mixed passenger-freight traffic. The GERT framework [18] applies to quantifying these residual sources; the low delay propagation coefficient (Table 2) confirms that a 10-minute disruption accumulates only 14 minutes of downstream impact under CTC management.

The Elin Pelin-Kostenets section, part of the Sofia-Plovdiv corridor, is progressing as the largest railway project in Bulgaria in recent decades. Divided into three subsections, it is being implemented under the Transport Connectivity Programme with a planned completion of end-2029. Upon completion, ETCS Level 2 and GSM-R will be deployed throughout, enabling full CTC integration across the reconstructed corridor.

5.2. Sofia-Burgas: Partial Modernisation

The Sofia-Burgas corridor (402 km) is the longest and most operationally complex intercity axis in Bulgaria, connecting the capital with the Black Sea coast and carrying mixed long-distance passenger, regional, night-train, and seasonal services. CTC covers approximately 62% of the route; GSM-R is available on only 47% of the line; ETCS Level 1 is partially deployed; legacy DPS/ETK systems remain active on 53% of the corridor. The mean delay of 18.6 minutes and the punctuality rate of 61.7% reflect this technological fragmentation.

The corridor's performance is particularly sensitive to initial disruptions at the western end of the line, which propagate across multiple intermediate stations before reaching the coast. The delay propagation dynamics on legacy segments—where the absence of automated conflict detection means that a 10-minute initial disruption generates a 31-minute expected network accumulation within two propagation steps, compared to 14 minutes under CTC—explain why seasonal

peaks, when traffic density is highest, produce disproportionate deterioration in punctuality. The simulation modelling approach developed in [19] is directly applicable to this corridor and could provide the quantitative basis for prioritising specific modernisation investments.

Full modernisation-GSM-R, ETCS Level 2, SCADA-CTC integration-is projected, by analogy with comparable EU corridors, to raise punctuality by 20-25 percentage points, with corresponding gains in passenger comfort and competitive parity with the Sofia-Plovdiv axis. The delay baseline established by Karagyozov and Todorova provides the reference against which post-modernisation improvements should be assessed.

5.3. Competitive Implications

The delay propagation differential ($\delta = 0.64$ on Line 1 vs 1.30 on Sofia-Burgas, Table 2) translates into competitive asymmetry: a 10-minute disruption attenuates to 14 min on the modernised corridor but amplifies to 31 min on the legacy one. This 2.2-fold difference is a structural consequence of interlocking technology, not of traffic volume or operator quality: Line No. 1 (TEN-T magistrale) benefits from active EU cohesion funding. At the same time, the Sofia-Burgas corridor operates without an equivalent programme, imposing a punctuality ceiling that no operational excellence can overcome. The Logit choice model [21] confirms that this infrastructure gap translates directly into a passenger-attraction disadvantage for new entrants. At the same time, regional benchmarking by Stoilova [44] shows that Bulgarian performance deficits are most pronounced precisely on those dimensions linked to dispatcher system capability.

Charge design alone cannot resolve this asymmetry [27]: the fundamental requirement is infrastructure harmonisation on the Sofia-Burgas and Plovdiv-Burgas corridors, without which the Fourth Railway Package's non-discrimination framework cannot produce genuinely equal competitive conditions.

The 2026 PSO contracts sharpen this competitive asymmetry. Line No. 3 crosses all three lots: the TRIS CTC-managed Iliyantsi-Karlovo section (BDZh, Western Region) benefits from automated conflict detection and real-time tracking, while the continuation through the Southern and Northern Regions - operated by Ivkoni Express - lacks equivalent CTC coverage. Delays in legacy segments cannot be clearly attributed to either infrastructure failure or operator management, undermining the PSO contractual transparency that Regulation (EC) 1370/2007 requires [2]. Ivkoni Express thus bears the operational consequences of legacy infrastructure it neither owns nor controls. Accelerating the deployment of CTC and GSM-R on the Plovdiv-Burgas and Karnobat-Varna sections is a prerequisite for the equitable operation of the 2026 PSO contracts.

6. CONCLUSIONS

This paper has examined the current state of dispatcher systems in Bulgaria and their implications for the operational performance and liberalisation of the passenger rail market. The analysis, grounded in prior research on delay analysis, simulation modelling, passenger comfort, and intelligent management systems, leads to four principal conclusions.

First, the technological heterogeneity of Bulgarian dispatcher systems leads to measurable, significant operational disparities across corridors. Corridors equipped with modern CTC, GSM-R, and ETCS achieve substantially better punctuality and delay containment than legacy-equipped routes, confirming the findings of delay analyses and simulation studies conducted on the Bulgarian network.

Second, punctuality is the primary determinant of passenger comfort and modal choice in the Bulgarian context, as established by comfort-indicator research and modal-choice modelling. Dispatcher modernisation therefore generates direct commercial value: improved punctuality translates into higher passenger satisfaction, greater willingness to use rail, and stronger operator revenue potential.

Third, the transition to intelligent management systems is not simply a technological upgrade but a qualitative transformation of the dispatcher function. Modern systems reduce operational variance-and thus the unpredictability that passengers find most damaging-in ways that legacy platforms cannot replicate. Realising this potential requires not only hardware deployment but also the retraining and qualification of dispatcher personnel to operate new systems effectively.

Fourth, the modernisation of the dispatcher system is a strategic prerequisite for the successful liberalisation of Bulgaria's passenger rail market. The performance differential between the Sofia-Plovdiv and Sofia-Burgas corridors demonstrates that formal non-discrimination requirements cannot produce genuine competitive equality when infrastructure capabilities vary materially across routes. Completing the modernisation programme on the Sofia-Burgas and Plovdiv-Burgas corridors is therefore not merely a technical investment but an institutional prerequisite for a well-functioning open market.

Future research should validate these conclusions through post-modernisation performance monitoring as the NRIC upgrade programme progresses. It should explore the application of real-time management system architectures developed for marshalling yards and passenger complexes to the broader network-level dispatcher system design.

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