DOI: 10.2507/37th.daaam.proceedings.xxx

INFLUENCE OF INTERLOCKING MODERNISATION ON RAILWAY STATION OPERATIONS AND CAPACITY: A CASE STUDY OF KRIŽEVCI RAILWAY STATION

Hrvoje Haramina, Adrian Wagner & Ružica Barišić

Working Paper of 37th DAAAM Symposium

This Publication has to be referred as: Haramina, H[rvoje]; Wagner, A[drian] & Barišić, R[užica] (2026). Influence of Interlocking Modernisation on Railway Station Operations and Capacity: A Case Study of Križevci Railway Station, Proceedings of the 37th DAAAM International Symposium, pp.xxxx-xxxx, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-xx-x, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/37th.daaam.proceedings.xxx

Abstract

Railway interlocking systems ensure safe train movements by establishing and maintaining dependencies between signals, points, track sections and train routes. Although relay-based interlockings can provide a high level of safety and reliability over long periods of operation, railway infrastructure modernisation increasingly involves their replacement by electronic interlocking systems. This paper investigates the operational effects of replacing the relay-based SpDrL-30 interlocking with the SIMIS W electronic interlocking at Križevci railway station in Croatia. A comparative case-study approach is applied, focusing on route setting and release, infrastructure monitoring, safety functions, fault diagnostics and system adaptability. The analysis indicates that the main changes resulting from interlocking modernisation are related to computer-based traffic control, improved system monitoring and diagnostics, automation of selected safety-related processes and greater adaptability to future infrastructure and operational requirements. Particular attention is given to route locking and release, since the period during which infrastructure elements remain unavailable for conflicting train routes represents a potential link between interlocking operation and station capacity. The study identifies operational parameters suitable for subsequent quantitative evaluation using microscopic railway traffic simulation.

Keywords: Relay-based interlocking system; electronic interlocking system; Križevci railway station; railway traffic management; station capacity.

1. Introduction

Railway interlocking systems are essential for safe railway traffic control, preventing conflicting train and shunting movements by establishing and maintaining dependencies between signals, points, track sections and other infrastructure elements. Their technological implementation has evolved from mechanical and electromechanical systems through relay-based technology to contemporary computer-based electronic interlockings [1].

Despite this development, different generations of interlocking technology continue to coexist on European railway networks. Bădău [1] demonstrated that relay-based interlockings still account for a substantial proportion of installed systems in 15 European countries. The Croatian railway network is similarly characterised by the coexistence of different signalling and interlocking technologies, making their modernisation an important component of railway infrastructure development. However, replacing a relay-based interlocking with an electronic system does not necessarily imply replacing unsafe or unreliable technology. Relay-based systems operate according to fail-safe principles and have provided reliable service for decades. The relevant research question is therefore how technological replacement changes operational processes and whether these changes may affect infrastructure utilisation and railway station capacity. Railway station capacity depends not only on infrastructure layout but also on operational and signalling conditions. Previous research has demonstrated the importance of traffic control technology, infrastructure configuration, route conflicts and operational time components for station capacity [2]. The UIC 406 methodology further establishes a framework for assessing railway infrastructure capacity, including railway nodes [4].

The present paper examines the replacement of the SpDrL-30 Iskra Lorenz relay-based interlocking with the SIMIS W electronic interlocking at Križevci railway station in Croatia, implemented as part of the reconstruction and double-tracking of the Dugo Selo–Križevci railway section. The objective is to identify and classify the operational changes resulting from this technological replacement and determine which changes may be relevant for subsequent quantitative assessment of railway station capacity.

Railway interlocking systems ensure that train and shunting routes can only be established when the required safety conditions are fulfilled. While relay-based systems implement safety dependencies primarily through electrical circuits and safety relays, electronic interlockings employ safety-related computer hardware and software [1]. Previous research has also highlighted the importance of ergonomic workplace design in improving human–machine interaction [5]. In this context, the replacement of conventional control equipment with a computer-based graphical interface at Križevci railway station introduces a different mode of interaction between the traffic controller and the interlocking system, which may influence information accessibility and operational efficiency. Previous studies have also examined the influence of different signalling systems on railway infrastructure capacity [6], the relationship between operational processes, track occupancy and station capacity [7], and the effects of different route locking and release principles on the efficiency of railway station operations [8].

From an operational perspective, interlocking technology may influence human–machine interaction, information availability, diagnostics, maintenance and route management. Of particular relevance to railway capacity are route locking and release processes, which determine when infrastructure elements reserved for one train movement become available for subsequent conflicting movements. Wagner [2] investigated the influence of train and traffic control systems on railway station capacity, emphasising the importance of quantifying operational time components when assessing technological changes. His research indicates that more advanced control technology does not necessarily result directly in increased capacity, as the actual effect depends on signalling principles, infrastructure configuration and operational conditions. Haramina et al. [3] examined the relationship between railway station infrastructure layout, operational conflicts, safety and capacity using Turopolje railway station as a case study. Their research highlights the importance of infrastructure configuration and route conflicts in assessing station capacity mainly based of optimisation of train route overlaps. The UIC 406 methodology [4] provides a standardised approach to railway infrastructure capacity assessment based on timetable compression and includes principles applicable to railway nodes. This framework highlights the relevance of infrastructure occupation and operational time components in quantitative capacity assessment. Building on these, the present research focuses on the relationship between interlocking technology, operational processes and the temporal availability of railway station infrastructure. While previous research has addressed interlocking safety and railway capacity, the operational consequences of replacing relay-based interlocking with electronic interlocking warrant further investigation. The Križevci railway station case study addresses this interface by identifying changes in operational processes that may influence infrastructure availability and should therefore be considered in subsequent quantitative capacity assessment.

2. Research Method and Case Study

The research was conducted as a comparative case study of two successive generations of interlocking systems installed at the same railway station. The previous relay-based SpDrL-30 Iskra Lorenz system and the current SIMIS W electronic interlocking at Križevci railway station were analysed. The analysis is based on station operating documentation [9] and technical and operating instructions describing the two interlocking systems. The functional characteristics and operating procedures were systematically compared according to five groups of criteria:

1. route setting, locking and release;
2. monitoring of infrastructure occupancy and system status;
3. safety-related functions;
4. fault registration and diagnostics;

Working Paper of 37th DAAAM Symposium

5. maintenance and adaptability to infrastructure and operational changes.

The analysis was conducted in two stages. First, the principal functional and operational differences between the two generations of interlocking were identified. Second, the identified changes were classified according to their implications for railway traffic management and their potential relevance for station capacity. Particular attention was paid to processes affecting the period during which infrastructure elements remain reserved or locked for a particular train route. From a capacity perspective, this period is relevant because a conflicting route cannot be established until the infrastructure elements required for that route become available.

The research is primarily qualitative and functional. A consistent before-and-after dataset containing route occupation times, delays, system availability or realized station capacity was not available. Consequently, the capacity implications identified in this study are interpreted as mechanisms and parameters with a potential capacity effect rather than as quantitatively demonstrated capacity gains.

Križevci railway station is located on railway line M201 State Border–Botovo–Koprivnica–Dugo Selo and also functions as a junction station for line L203 Križevci–Bjelovar–Kloštar. The station serves passenger and freight traffic and has twelve tracks, including six main and six secondary tracks [9]. Before infrastructure modernisation, Križevci station was equipped with the SpDrL-30 Iskra Lorenz relay-based interlocking. The system enabled central control of points, derailers, entrance and exit signals, shunting signals and level-crossing protection equipment [10]. The SpDrL-30 was operated from a physical control panel containing a schematic representation of the station track layout. Commands were entered by means of physical buttons, while the traffic controller monitored the status of signals, points, routes and track occupancy through light indications. Track occupancy was detected using track circuits. Train-route setting required operation of the corresponding start and destination controls. The interlocking subsequently checked the conditions required for safe train movement, including the availability of the required infrastructure elements and the correct position of relevant points. After the safety conditions were fulfilled, the required infrastructure elements were locked and the corresponding signal could authorize train movement [10].

As part of the modernization of the Dugo Selo–Križevci railway section, the relay-based interlocking was replaced by the SIMIS W electronic interlocking. The new system is operated through computer workstations using the VICOS OC 111 graphical user interface [11]. Infrastructure status and train movements are displayed graphically, while track occupancy is monitored using axle-counting equipment. The electronic system also enables electronic registration of operational events, disturbances and faults, providing additional information for traffic management and maintenance activities [11].

3. Results and Discussion

The most immediately visible change resulting from interlocking modernization concerns the interaction between the traffic controller and the signalling system. The SpDrL-30 system was operated through a physical control panel with buttons and light indicators, whereas SIMIS W uses a computer-based graphical interface. This represents a significant technological change in human-machine interaction, although the underlying safety objective remains unchanged. In both systems, a signal authorizing train movement can only be displayed after the interlocking has verified and secured the required route. The difference therefore concerns primarily the technological implementation of these dependencies and the manner in which commands and system information are exchanged between the traffic controller and the interlocking. The electronic interface provides a more detailed graphical representation of infrastructure status. Furthermore, electronic registration of system events, disturbances and faults provides additional information that can facilitate fault identification and diagnostics [11]. These changes may contribute to improved situational awareness and maintenance efficiency. However, the present study did not quantitatively investigate traffic-controller workload, user acceptance or the effect of the changed interface on response times. These aspects therefore cannot be considered demonstrated benefits and should be investigated separately.

From the perspective of station capacity, the most important aspect identified in the analysis concerns route locking and release. When a train route is established, the points and other infrastructure elements required for that route are secured and protected against commands that could create a conflicting movement. This locking is fundamental to railway safety. At the same time, however, it temporarily prevents the locked infrastructure elements from being used for another route. The operational sequence can be represented conceptually as follows: route setting (infrastructure locking) → train movement → route release → infrastructure availability → setting of a subsequent conflicting route.

The conditions under which the route, or individual infrastructure elements belonging to the route, can be released therefore influence the earliest possible moment at which another conflicting movement can be authorised. This observation represents an important interface between railway safety and railway capacity. Interlocking safety logic determines when an infrastructure resource may safely become available, whereas the timing of this availability influences the minimum operational separation between train movements requiring conflicting infrastructure.

Working Paper of 37th DAAAM Symposium

The comparison of the SpDrL-30 and SIMIS W systems shows that both implement the fundamental requirement of preventing conflicting routes. However, the technological implementation of route control and release differs. The electronic system incorporates route management within computer-based safety logic and provides the traffic controller with a more detailed representation of the status of individual infrastructure elements and established routes. The important difference regarding station capacity is that release of the overlap route on the relay-based interlocking system was possible immediately after clearing the switch track circuit and occupying the station track circuit, which the new system does not allow; instead, for safety reasons, the release is automatic after 30 seconds. The capacity effect of these differences cannot be determined directly from the functional comparison. Earlier availability of an infrastructure element only provides a capacity benefit if another train actually requires that resource during the relevant period. The practical effect therefore depends on infrastructure topology, timetable structure, sequence of train movements and the frequency and location of route conflicts. For this reason, route locking and route release should be considered capacity-relevant interlocking parameters, but their actual capacity effect must be determined for a specific infrastructure and traffic scenario. This finding provides a direct connection with previous research on train and traffic control and station capacity [2]. Whereas Wagner [2] examined how changes in train and traffic control influence operational time components and capacity, the present analysis identifies route locking and release as specific interlocking-related processes that should be included in such an assessment. The operational impact of the 30-second overlap release delay depends on the sequence and interaction of train movements. In high-density suburban passenger traffic, earlier overlap release may facilitate the timely setting of subsequent conflicting routes and potentially reduce minimum headways. This is also relevant for slower freight trains starting from the station or approaching the station from the opposite direction. Earlier availability of the required infrastructure may reduce the likelihood that an approaching freight train needs to decelerate or stop while waiting for a conflicting route to be released. Such interruptions can be particularly significant for freight trains due to their lower acceleration capabilities and the additional time required to regain operating speed. Consequently, the operational benefit of earlier overlap release is not limited to shorter headways but may also include smoother train movements and reduced secondary delays.

The comparison also indicates that the transition to electronic interlocking should not be interpreted simply as an increase in safety relative to the relay-based system. The SpDrL-30 was designed according to fail-safe principles and provided safe traffic management during its long period of operation. The principal difference is the technological means by which safety functions are implemented. In the relay-based system, safety dependencies are realized predominantly through relay circuitry, whereas SIMIS W implements corresponding functions through safety-related electronic hardware and software.

The Croatian regulatory framework defines the conditions under which railway traffic must be safely managed [12] and establishes principles of Croatian national train control system [13]. Interlocking operation therefore takes place within a regulatory framework that defines the required level of protection irrespective of the technological generation of the interlocking. From the capacity perspective, this distinction is important. The objective is not to reduce safety-related protection times merely to obtain additional capacity. Instead, advanced interlocking technology may enable more detailed monitoring of infrastructure and train status and allow infrastructure elements to become available as soon as all required safety conditions have been fulfilled. Consequently, the relationship between interlocking and capacity should be understood as the optimization of infrastructure availability within the constraints imposed by railway safety requirements.

The comparative analysis identified further operational differences that do not directly determine station capacity but can affect the overall operational performance of the station. The SIMIS W system enables electronic recording of system events, disturbances and faults. Such information can support faster fault localization and provide maintenance personnel with more detailed diagnostic information [11]. Electronic interlocking also offers greater flexibility for future infrastructure and operational modifications like centralization of railway traffic control and introduction of modern train control systems e.g. ETCS Level 2. Changes to relay-based systems may require extensive modifications of physical circuitry, whereas the modular architecture of electronic interlocking enables a different approach based on configurable hardware and software. Furthermore, one more important factor influencing the feasibility of replacing relay-based technology with modern electronic interlocking systems is the availability of spare parts for the maintenance of relay-based interlocking systems. Nevertheless, relay-based technology also has relevant operational characteristics. The SpDrL-30 system demonstrated robustness and reliability during long-term operation. Electronic equipment requires appropriately controlled environmental conditions and supporting technical systems. Therefore, modernization should not be interpreted as an improvement in every individual technical characteristic, but rather as a transition towards a different technological architecture with different operational and lifecycle characteristics. Table 1 summarises the main findings of the comparative analysis.

Working Paper of 37th DAAAM Symposium

Aspect	SpDrL-30	SIMIS W	Main operational implication	Capacity relevance
Traffic control	Physical control panel	Computer-based graphical interface	Changed human-machine interaction	Indirect
Infrastructure status	Light indications	Detailed graphical representation	Increased information availability	Indirect
Train detection	Track circuits (in this case study)	Axle-counting equipment (in this case study)	Different occupancy-detection concept	Potential
Route setting	Relay-based logic	Computer-based safety logic	Different implementation of route control	Potential
Route locking and release	Relay-based safety functions	Electronic safety functions	Determines infrastructure availability	Direct
Fault registration	Conventional indications	Electronic event and fault logging	Improved diagnostic information	Indirect
Spare parts availability	Limited availability of spare parts	Spare parts readily available	Improved maintainability and reduced risk of prolonged system downtime	Indirect
System modification	Hardware-intensive	Modular/configurable architecture	Greater adaptability	Long-term/indirect

Table 1. Main operational effects of interlocking modernization at Križevci railway station

The central result of the analysis is therefore not that the electronic interlocking replaces an inherently unsafe relay system. Both systems are intended to provide safe train movements. Rather, modernization changes the technological and operational mechanisms through which safety functions are implemented, infrastructure status is monitored and railway infrastructure becomes available for successive train movements.

From the perspective of station-capacity research, the most important result is the identification of route locking and release as the operational mechanism through which interlocking technology can directly affect infrastructure occupation time and consequently the temporal availability of conflicting routes.

4. Conclusion

This paper analyzed the operational effects of replacing the SpDrL-30 relay-based interlocking by the SIMIS W electronic interlocking at Križevci railway station. The analysis indicates that the previous relay-based system provided robust and safe railway traffic control and that the significance of modernization should therefore not be interpreted simply as the replacement of an inadequate safety system. The principal changes associated with the electronic interlocking concern computer-based traffic control, more detailed information on infrastructure and system status, electronic event and fault recording, enhanced diagnostic possibilities and greater adaptability to future infrastructure and operational modifications. The analysis also identifies an important relationship between interlocking operation and railway station capacity. Infrastructure elements forming a train route remain unavailable for conflicting movements while they are locked by the interlocking. Consequently, route-release conditions influence the earliest moment at which these resources can become available for a subsequent conflicting route.

The principal contribution of the study is therefore the systematic identification and classification of the operational effects of interlocking modernization according to their relevance for railway traffic management and their potential influence on station capacity. The results indicate that not all benefits of electronic interlocking have the same relationship with capacity. Improved diagnostics and system monitoring primarily affect operational quality, reliability and maintenance, whereas route locking and release can directly affect the temporal availability of infrastructure for conflicting train movements. The study has several limitations. Most importantly, a consistent quantitative dataset describing comparable operational conditions before and after interlocking modernization was not available. Consequently, the results do not demonstrate that implementation of SIMIS W increased the capacity of Križevci railway station. Instead, the study identifies the mechanisms and parameters through which an effect on capacity may occur.

Further research should focus on quantitative evaluation of these parameters. Following the methodological direction of previous research on the influence of train and traffic control on railway station capacity [2], a microscopic simulation model of Križevci railway station could be developed. The model should explicitly represent route-setting processes, route-locking and release conditions, infrastructure occupation and relevant sequences of conflicting train movements.

Working Paper of 37th DAAAM Symposium

Different interlocking and operational scenarios could subsequently be compared using indicators such as minimum time intervals between conflicting movements, infrastructure and route occupation times, train waiting times and the number of feasible train movements within a defined analysis period. Such an approach would make it possible to quantify the capacity effects identified conceptually in the present study and to distinguish between technological improvements that primarily affect safety, maintenance or traffic management and those that result in measurable improvements in railway station capacity.

The proposed approach could subsequently be applied to other railway stations equipped with different generations of interlocking systems. This would enable the development of a broader methodological framework for evaluating the operational and capacity effects of railway interlocking modernization.

5. References

[1] Bădău, F. (2022). Railway interlockings – A review of the current state of railway safety technology in Europe, Promet – Traffic&Transportation, Vol. 34, No. 3, pp. 443-454, ISSN 0353-5320, DOI: 10.7307/ptt.v34i3.3992.

[2] Wagner, A. (2024). Influence of train and traffic control on railway station capacity, Ph.D. Dissertation, Institute of Transportation Sciences, Faculty of Civil and Environmental Engineering, Technische Universität Wien, Vienna, Austria, DOI: 10.34726/hss.2024.123221.

[3] Haramina, H.; Vrančić, D.; Wagner, A. & Lončar, D. (2021). Optimization of railway station infrastructure layout in the function of rail safety and capacity improvement – Case study Turopolje railway station, Proceedings of the International Scientific Conference "The Science and Development of Transport" (ZIRP 2021), Šibenik, Croatia, ISSN 2718-5605, Ivanjko, E.; Stanković, R. & Nikšić, M. (Eds.), pp. 55-60, Faculty of Transport and Traffic Sciences, University of Zagreb, Zagreb, Croatia.

[4] International Union of Railways (UIC) (2013). Capacity, UIC Code 406, 2nd Edition, International Union of Railways, ISBN 978-2-7461-2159-1, Paris, France.

[5] Vujica Herzog, N. & Buchmeister, B. (2023). Ergonomic workplace design using motion capture technology, Chapter 01 in DAAAM International Scientific Book 2023, pp. 001-016, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-39-6, ISSN 1726-9687, Vienna, Austria, DOI: 10.2507/daaam.scibook.2023.01.

[6] Goverde, R. M. P.; Corman, F. & D'Ariano, A. (2013). Railway line capacity consumption of different railway signalling systems under scheduled and disturbed conditions, Journal of Rail Transport Planning & Management, Vol. 3, No. 3, pp. 78-94, ISSN 2210-9706, DOI: 10.1016/j.jrtpm.2013.12.001.

[7] Nie, L. & Hansen, I. A. (2005). System analysis of train operations and track occupancy at railway stations, European Journal of Transport and Infrastructure Research, Vol. 5, No. 1, ISSN 1567-7141, DOI: 10.18757/ejtir.2005.5.1.4331.

[8] Wang, Y. & Li, X. (2022). Optimality analysis of train platforming and routing with different interlocking modes, Communications in Transportation Research, Vol. 2, Article 100061, ISSN 2772-4247, DOI: 10.1016/j.commtr.2022.100061.

[9] HŽ Infrastruktura (2024). Railway Station Operating Regulations, Part I – Križevci (Poslovni red kolodvora I. dio – Križevci), HŽ Infrastruktura, Zagreb.

[10] HŽ Infrastruktura. Operating instructions for the SpDrL-30 Iskra Lorenz electro-relay interlocking system at Križevci railway station (Uputa za rukovanje elektro-relejnim signalno-sigurnosnim uređajem SpDrL-30 Iskra Lorenz, kolodvora Križevci). HŽ Infrastruktura, Zagreb.

[11] HŽ Infrastruktura. Instructions for the operation and functioning of the SIMIS W electronic interlocking system (ESSU) at Križevci railway station on railway lines M201 and L203 Križevci–Bjelovar–Kloštar (Uputa o rukovanju i načinu funkcioniranja elektroničkog signalno-sigurnosnog uređaja (ESSU) SIMIS W kolodvora Križevci na pruzi M201 i pruzi L203 Križevci–Bjelovar–Kloštar), HŽ Infrastruktura, Zagreb.

[12] Ministry of the Sea, Transport and Infrastructure of the Republic of Croatia (2016). Ordinance on the method and conditions for the safe conduct and management of railway traffic (Pravilnik o načinu i uvjetima za sigurno odvijanje i upravljanje željezničkim prometom), Narodne novine, No. 107/2016.

[13] Ministry of Maritime Affairs, Transport and Infrastructure of the Republic of Croatia (2015). Ordinance on the meaning and use of signals, signalling signs and signalling marks in railway traffic (Pravilnik o značenju i uporabi signala, signalnih znakova i oznaka u željezničkom prometu), Narodne novine, No. 94/2015.

Working Paper of 37th DAAAM Symposium