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From Written to Digital Commands in German Railway Operations – Challenges and Opportunities

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ABSTRACT

Safe communication between dispatchers and train drivers is a central element of railway operations, especially in disruption scenarios where commands ensure the continuation of safe operations. Traditionally, this process has been carried out in written or telephone form according to clearly standardised rules set out in DB Guideline 408. With the introduction of digital command, a profound change is taking place in this safety-critical communication. The aim of this study is to systematically examine the effects of digitalisation on comprehensibility, usability and safety. Methodologically, the research employs both qualitative and quantitative approaches, including simulator studies, task analyses, guided interviews, questionnaires, mock-ups and thinking-aloud techniques. Initial assessments indicate that digital commands provide significant benefits in terms of time savings, standardisation and documentation, but also introduce new challenges related to human-machine interaction and increased demands on cognitive processes. Factors such as stress, time pressure and user habits significantly influence acceptance and error proneness. The study shows that digital commands can only unfold their full potential if technical innovation and human factors are equally addressed. This research contributes to a deeper understanding of how digitalisation can enhance safety and efficiency in railway operations without compromising the existing high safety standards.

KEYWORDS

digital command; railway operations; human factors.

1. INTRODUCTION

Safety-critical communication is a fundamental component of railway operations and is essential for maintaining a high level of operational safety, particularly in complex or time-critical situations. During disruption management, when deviations from standard procedures occur, operational commands play a central role in restoring order and ensuring the safe continuation of train movements. Miscommunication in this context can have significant consequences: misunderstandings or incorrect transmissions may not only cause delays but can also escalate into safety-critical situations or accidents. For this reason, the wording, structure and sequence of commands have traditionally been strictly standardised to eliminate ambiguities. With the increasing digitalisation of the railway sector, however, this long-established framework is undergoing fundamental change. Digital command systems promise faster transmission, improved documentation and reduced susceptibility to communication errors. At the same time, they introduce new challenges regarding human–machine interaction, cognitive workload and acceptance among operational staff. These developments raise important questions about how digitalisation affects safety-critical communication and how national and European regulatory frameworks, such as DB-Guideline 408 and TSI OPE 2019/773, shape the transition from written to digital commands. The aim of this study is to systematically analyse these changes by examining the German command system in the context of emerging digital solutions and situating it within a broader European framework. By combining analysis of the regulatory environment, examination of digital command concepts and a research-oriented methodological approach, this work provides insight into the opportunities and challenges associated with the digitalisation of operational commands in railway operations [1–6].

2. COMMANDS IN GERMAN RAILWAY OPERATIONS

2.1 Written command in Germany

The national system of written commands in Germany is regulated in DB Guideline 408 and has formed a central element of safe railway operations for decades. The structure comprises a total of 14 standardised commands, recorded in a uniform form. On the front side of the form, the commands themselves are listed, while the reverse side contains the corresponding reasons. The procedure for issuing commands is defined in Guideline 408.0341 [1], and the procedure for receiving commands is defined in Guideline 408.0351 [1]. Communication follows a closed-loop principle: the dispatcher dictates the command, the train driver repeats it verbatim, and the dispatcher finally confirms the correct reproduction. Typical applications include passing a signal at danger, the implementation of temporary speed restrictions, or conducting a reverse movement.

With the introduction of the new command form, both the structure and the numbering of commands are fundamentally revised. The table of command reasons receives a new system and includes additional reasons that were previously not included. In addition, the individual entries within the commands are distinguished by specific identifiers for options and tasks. To ensure compatibility with the digital application, the input mask for creating and issuing commands is being redesigned. As a result, different command variants can also be displayed in the digital application in the future. All elements of the commands – including identifiers, labels and checkboxes – must be visible in every view. In the written form, options that may appear in multiple commands will in future be identified by a code consisting of an “x” followed by a dot and a two-digit number (e.g. x.25 or x.90). In the digital procedure, however, the “x” is replaced by the corresponding command number, so that, for example, the identifier x.25 in Command 1 becomes 1.25 [1–3].

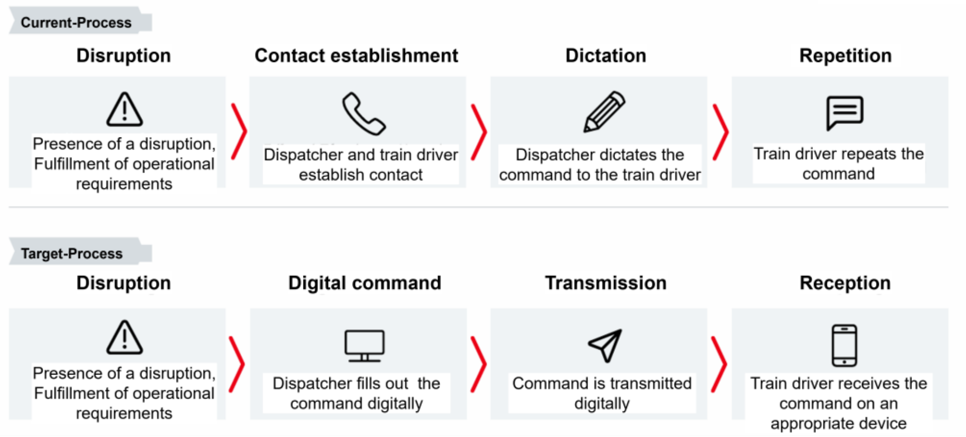

Figure 1 – Comparison between the current process and target process of command transmission [4]

2.2 European command TSI

At the European level, operational command procedures are defined in the TSI OPE (2019/773), which specifies seven harmonised command forms for ETCS operation. These commands apply exclusively to movements under ETCS supervision and therefore do not cover the full spectrum of operational scenarios encountered in mixed-traffic environments. Germany, however, requires fourteen command types to support both ETCS and conventional signalling, as well as national operational procedures that exceed the scope of TSI OPE. Consequently, the numbering and structure of the new German command form do not correspond to the TSI OPE command numbering. With the timetable change on 14 December 2025, Germany will introduce a revised command form that follows a hybrid approach, integrating the wording and structural principles of the European model while retaining additional national commands. This explains why the new German command form cannot adopt the TSI numbering scheme and why a purely TSI-based command system is not operationally feasible in the current German network. The development of the digital command further addresses this gap, as TSI OPE does not define a digital transmission method for operational orders outside the ETCS context [1, 2, 7].

2.3 Digital command

The digital command fundamentally changes the previous communication process, as dictation and verbal repetition are no longer required. Instead, the dispatcher creates the command directly in the system and uploads it to a central server. The affected train driver then receives a TAN (transaction number) with which they can log into the system to view the command. After reading, the command must be actively confirmed, providing the dispatcher with feedback that the instruction has been transmitted, understood and acknowledged. The digital command offers several advantages. By eliminating dictation and repetition, significant time savings are achieved, particularly in high-pressure disruption scenarios. In the case of large-scale disruptions, commands can also be transmitted more quickly and in a standardised form, as predefined digital templates are available to the dispatcher. The information is displayed in a uniform interface, reducing media discontinuities. Furthermore, commands can be digitally archived, resulting in paperless documentation and more efficient traceability. Despite these advantages, the digital command presents several challenges. Its use depends heavily on a stable IT infrastructure and sufficient network coverage. Risks also arise from the TAN-based authentication procedure, such as technical errors or incorrect inputs. Additional usability issues may occur due to different devices, operating systems and newly designed user interfaces. Another key aspect concerns the implementation itself. Although the digital command is scheduled to be introduced nationwide on 14 December 2025, the rollout will initially be limited to specific, red-marked routes [8]. This leads to a fragmented application, as traditional command procedures will continue to be used in parallel. Railway undertakings have been informed, and training tools for train drivers have been provided, but acceptance remains a critical factor. The voluntary use of the system during the initial phase may result in operational inconsistencies and the risk of divergent practices in daily operations [2–6].

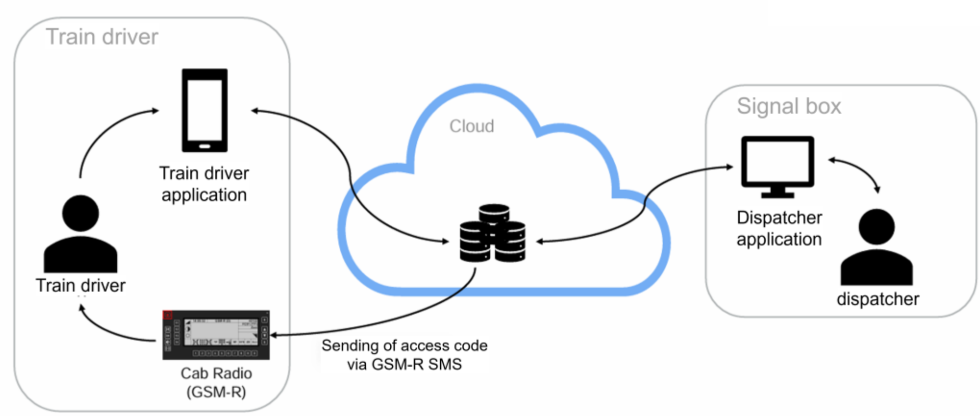

Figure 2 – Communication process between the dispatcher and train driver (digital command) [4]

2.4 European example

A highly relevant European example of digitalising operational command procedures can be observed in Austria. With the 2025 timetable period, ÖBB-Infrastruktur AG will introduce the "electronic command" as the mandatory standard, fully replacing the existing paper-based command forms. In contrast to the German deployment, which starts on selected routes and on a voluntary basis, the Austrian implementation is compulsory once introduced. The system is closely aligned with the harmonised command structure defined in the TSI OPE (2019/773), which specifies seven standardised instructions for ETCS operation. Beyond this regulatory alignment, the Austrian solution integrates several digital components, including secure data interfaces such as ZFM and infraDOAS, as well as the newly developed communication platform "dilocsync", through which commands are generated, transmitted and acknowledged electronically. Train drivers are required to use certified mobile devices capable of receiving, displaying and confirming commands; the provision of suitable hardware lies with the railway undertakings. In case of system unavailability, clearly defined fallback procedures apply, allowing either the "Sammelbefehl" (national fallback command form) or traditional paper-based orders. The Austrian approach, therefore, represents a fully digitalised, infrastructure-controlled and TSI-compliant command system that differs substantially from the hybrid German model, which combines national and European elements and relies on partial voluntary usage. This comparison illustrates the diversity of digital command strategies across Europe and highlights the potential benefits of a fully harmonised implementation [9, 10].

3. CHALLENGES

The digital command system is still in its early stages and has not yet been extensively tested in practice. With the timetable change on 14 December 2025 [2], its use will be introduced on a voluntary basis. In this context, dispatchers and train drivers will independently decide whether to apply the digital command, while the responsibility for operational safety will remain with the individuals involved. Such voluntariness is expected to limit both acceptance and consistent application. Furthermore, the implementation will not be nationwide but confined to selected routes. As illustrated in the official overview map, certain sections will support digital commands, whereas adjacent routes will continue to rely exclusively on written procedures. This fragmented availability may lead to situations in which drivers and dispatchers are required to alternate between digital and written commands within the same journey. In practice, such inconsistencies could discourage use, as personnel may choose to revert entirely to the established written procedure. With the introduction of the timetable change, these challenges will need to be closely monitored in operational practice and systematically analysed within the scope of the research project [2, 8, 11].

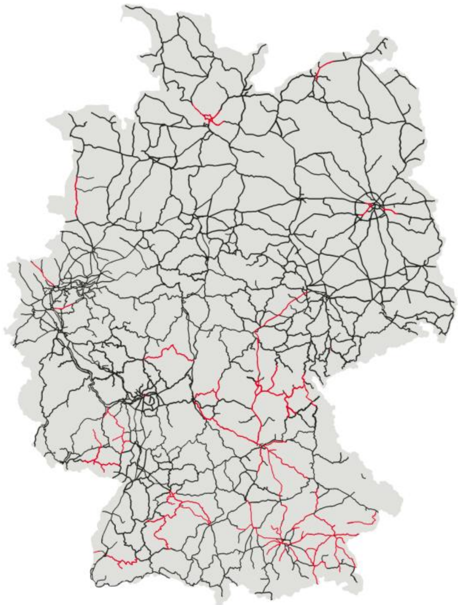

Figure 3 – Initial deployment areas of the digital command system in Germany [8]

4. METHODOLOGY

4.1 Simulation

(a) *(b)*

Figure 4 – Facilities at the department of railway operations and infrastructure (a) train driving simulator, (b) electronic interlocking

At the Technische Universität Berlin, Department of Railway Operations and Infrastructure, a comprehensive operations field is available that reproduces all interlocking technologies currently in use in Germany. This facility has long been employed for teaching purposes, training of external companies, and research projects, including, for example, the ARTE project in which tablet-based control was tested. The infrastructure is complemented by a driving simulator, which is likewise used for education, training and research. For the present project, the operations field and the driving simulator are combined in order to systematically investigate realistic scenarios. To this end, both the digital command system of Deutsche Bahn and a self-developed system are integrated into the operations field and applied alternately during the experiments. The participants assume the role of either train driver or dispatcher and are instructed to verbalise their actions while performing the assigned tasks. Eye movements are recorded using an eye-tracking device, while additional video and photographic documentation is collected. Structured debriefings follow each session, during which participants are asked to describe challenges, difficulties, positive and negative experiences, and to provide suggestions for improvement.

4.2 Interviews, questionnaires and mock-up surveys

In addition to the simulations conducted in the operations field, interviews and questionnaires are planned with train drivers and dispatchers who interact with the digital command system. The aim is to collect assessments of system usage, acceptance, perceived usefulness and route-specific characteristics. Furthermore, participants are asked to create mock-ups to visualise their expectations regarding the functionality, layout and integration of the digital command into existing work processes. This approach generates a combination of qualitative and quantitative data that can be used for further analysis. To ensure comparability, the questionnaires include Likert-scale items as well as open-ended questions, allowing both statistical evaluation and deeper insights into individual user perspectives. In addition, the System Usability Scale (SUS) is applied to obtain a standardised measure of usability across different systems. The surveys are conducted both after simulator-based test runs and as part of a longitudinal assessment accompanying the operational introduction of the digital command system. This makes it possible to evaluate the extent of system usage, overall acceptance among train drivers and dispatchers, and practical difficulties encountered during everyday operation. The collected data support an early evaluation of adoption patterns and provide a basis for identifying usability issues and potential improvements during the rollout phase [5, 12, 13].

4.3 Integration of results

Upon completion of the data collection, all results are subjected to a comprehensive analysis. The evaluation focuses on usability, performance and acceptance of the system. In addition, the development of usage over the course of the introduction is examined to determine whether initial reluctance diminishes with experience or whether initial enthusiasm subsides over time. By comparing the different experiences – with the DB system, the self-developed system and the mock-ups produced during the surveys – robust insights are expected to be gained for the development of a new, optimised command process. These findings will form the basis for the concluding summary and the outlook on future research activities [5].

5. CONCLUSION

The digital command represents a major milestone in the digitalisation of railway operations. It introduces fundamental changes to communication processes that have long relied on written and verbal procedures. While the system promises significant improvements in efficiency, standardisation and documentation, its successful implementation will ultimately depend on the human factors involved. Acceptance, usability and operational reliability remain decisive for ensuring that the high safety standards of railway operations are maintained. The methodological framework outlined in this study – combining simulations, interviews, questionnaires, usability analyses and error classifications – provides a systematic approach to evaluating the strengths and weaknesses of the digital command. By integrating both the Deutsche Bahn system and a self-developed prototype into realistic test environments, valuable insights can be generated into the operational, technical and human dimensions of the system [5].

As the nationwide introduction begins with the timetable change in December 2025 [2], it will be crucial to monitor acceptance and performance across different routes and operational contexts. Particular attention should be paid to fragmented deployment and the voluntary use of the system, which may hinder consistent application. Future research will therefore need to examine how user behaviour evolves over time and how digital commands can be further optimised to balance efficiency with the established culture of safety in railway operations.

The main contribution of this paper lies in identifying the key human-factors-related challenges that accompany the transition from written to digital command procedures and in outlining a structured methodological framework for their systematic analysis. Future research should therefore focus on measuring the impact of digital commands on situational awareness, error resistance and communication efficiency, and on identifying user groups that may require additional support or adapted interface designs. These steps will be essential to ensure that digital commands enhance operational performance without compromising the established culture of safety in railway operations.

DISCLAIMER

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