

THE IMPORTANCE OF THE HUMAN FACTOR IN DECISION-MAKING IN RAIL TRANSPORT

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Abstract

This study presents a railway-specific bibliometric and thematic mapping analysis of research on the human factor in railway decision-making. Using the Web of Science Core Collection, a structured screening procedure was applied to publications indexed between 2014 and 2024. After successive filtering stages, 27 peer-reviewed, railway-focused articles were retained for the railway-specific bibliometric mapping, complemented by 2 methodological references from adjacent high-risk or decision-analytic domains to contextualize underexplored aspects of multi-criteria prioritization and cognitive-error analysis. Bibliometric mapping was conducted with VOSviewer to examine keyword co-occurrence structures and co-authorship networks. The analysis identifies three thematic clusters: formal decision-support and multi-criteria modeling frameworks, operational human performance and safety-related cognitive processes, and integrative socio-technical system perspectives. The findings suggest that automation reshapes rather than eliminates human cognitive demands, reinforcing the importance of situational awareness, workload regulation, and trust calibration in railway operations. The study contributes by moving beyond descriptive mapping toward a railway-specific socio-technical interpretation of how decision-support models, automation, and operator cognition intersect. It also highlights a structural gap: formal railway decision-support models rarely incorporate dynamic cognitive-performance indicators such as workload, fatigue, situational awareness, trust calibration, and human reliability. The findings outline implications for human-centered automation governance and reliability-informed safety management.

Keywords: railway safety; human factor; decision-making; human reliability; automation

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1. INTRODUCTION

Railway systems are among the safest modes of land transport, yet their operational reliability remains strongly dependent on human cognition and performance. Even amid increasing automation, railway operations continue to function as complex socio-technical systems in which train drivers, traffic controllers, maintenance personnel, and system operators make safety-critical decisions under time pressure, uncertainty, workload variation, and environmental complexity. Consequently, railway safety cannot be explained solely by technical reliability, procedural compliance, or infrastructure performance; it also depends on the interaction among cognitive capacities, system design, and organizational conditions.

Research in ergonomics, transportation psychology, and safety science has repeatedly shown that railway decision-making is shaped by situational awareness, fatigue, psychological workload, trust in automation, and adaptive judgment. Train drivers and traffic controllers must continuously monitor dynamic operational states, interpret signals and automated outputs, anticipate emerging risks, and intervene when system behavior becomes uncertain or anomalous. Fatigue and workload have been associated with variability in operational performance and human reliability, while situational awareness and mental models support adaptive decision-making in dynamic traffic-control contexts (Filtness & Naweed, 2017; Harrison *et al.*, 2022; Lo *et al.*, 2016). These demands become particularly relevant in highly automated environments, where technology may reduce some forms of manual control while simultaneously increasing supervisory monitoring, trust calibration, and cognitive transparency requirements (Balfe *et al.*, 2018; Papadimitriou *et al.*, 2020). In this sense, automation does not eliminate the human factor; rather, it transforms the cognitive profile of railway work.

Despite the acknowledged importance of human factors in railway safety, the literature remains dispersed across several disciplinary traditions, including cognitive psychology, ergonomics, transportation engineering, operational research, and safety management. Some studies examine fatigue, workload, situational awareness, and human reliability at the operational level, whereas others focus on decision-support modeling, multi-criteria evaluation, disruption management, or automation architecture. This fragmentation limits the development of an integrated understanding of how the cognitive-operational and modeling-oriented research streams jointly contribute to knowledge of railway decision-making.

Bibliometric and thematic mapping approaches are suitable methods for clarifying this structure, as they enable the identification of recurrent conceptual patterns, thematic clusters, and collaboration networks within a defined research corpus. Unlike broad transportation reviews that combine railway, road, aviation, and maritime contexts, a railway-restricted synthesis can preserve domain specificity and reveal how the human factor is conceptualized within rail operations. Such an approach is particularly relevant as rail systems move toward greater digitalization, automation, and systemic interdependence, making the alignment between human cognition and technological design increasingly important.

The present study addresses this gap by conducting a railway-specific bibliometric and thematic analysis of research focused on the human factor in decision-making. The study maps the conceptual structure of the field, examines the connection between formal decision-support approaches and operational human performance research, and identifies areas where modeling-oriented and human reliability-oriented perspectives remain insufficiently integrated. Its contribution is threefold. First, it preserves the specificity of railway operations rather than merging rail evidence into broader transportation reviews. Second, it interprets the bibliometric structure through a socio-technical lens, showing how decision-support models, automation, and cognitive performance are connected within railway safety research. Third, it translates the observed thematic structure into practical implications for fatigue management, workload-sensitive safety assessment, automation transparency, simulator-based training, and reliability-informed decision-support design. Accordingly, the study is guided by the following research questions:

RQ1: What thematic structures characterize railway human-factor research in decision-making contexts?

RQ2: How are decision-support modeling approaches conceptually connected to operational cognitive performance research?

RQ3: What structural gaps exist between modeling-oriented and human reliability-oriented research streams in railway safety studies?

The theoretical positioning of the review is grounded in contemporary socio-technical systems theory, systems ergonomics, resilience engineering, Safety-II, and human-systems integration. These perspectives are particularly appropriate for railway decision-making because they treat safety as an emergent property of interactions among people, technologies, tasks, organizational arrangements, and operational environments rather than as a property of isolated components (Carayon, 2006; Provan *et al.*, 2020; Waterson *et al.*, 2015; Wilson, 2014). From this standpoint, the human factor is not reducible to error probability or individual compliance; it also includes adaptive capacity, monitoring, coordination, interpretation of automation, and the ability to maintain safe performance under variable conditions. Railway operations share this systemic profile with other high-reliability domains, including aviation and air traffic control, where safety depends on the joint calibration of automation, human expertise, procedural constraints, and organizational resilience. Nevertheless, railway systems also involve domain-specific features, such as fixed infrastructure, signaling regimes, level crossings, timetable constraints, and distributed traffic-control responsibilities, which justify a rail-specific synthesis.

Decision-making in rail transport occurs in safety-critical socio-technical environments characterized by time pressure, procedural constraints, automation, and potentially severe consequences of error. Railway personnel must continuously interpret operational signals, monitor system states, anticipate risks, and select appropriate responses under conditions of uncertainty. For this reason, railway decision-making cannot be understood as a purely procedural activity; it depends

on the interaction between perceptual accuracy, attention regulation, workload management, stress adaptation, and system design.

A central construct in this process is situational awareness, which supports the perception of relevant operational cues, comprehension of their meaning, and projection of future system states. In railway contexts, situational awareness is essential because operators often make decisions in dynamic environments where delayed interpretation or outdated mental models may increase operational risk. Research on train traffic control and operator resilience indicates that performance depends on stable mental models, goal management, and the capacity to adapt decisions to evolving traffic conditions (Lo *et al.*, 2016). When awareness deteriorates, the probability of delayed reactions, incorrect cue interpretation, and unsafe decisions increases.

Fatigue, stress, and psychological workload further influence railway decision-making by affecting vigilance, executive control, and behavioral regulation. Train drivers and other railway personnel frequently operate under conditions of prolonged attention, shift work, monotony, and intermittent high-demand events. Empirical studies show that fatigue and workload pressure are associated with performance variability and increased vulnerability to error in rail operations (Filtneß & Naweed, 2017; Harrison *et al.*, 2022). These findings indicate that decision reliability depends not only on professional competence but also on maintaining cognitive resources within sustainable limits.

Automation adds another layer of complexity. Although automated systems are designed to improve efficiency and reduce certain categories of human error, they also reshape the operator's role by introducing demands for supervisory control, passive monitoring, anomaly detection, and trust calibration. Human operators must understand automated outputs, evaluate system behavior, and intervene when necessary, often under time pressure and with incomplete transparency. Studies on human–automation interaction suggest that insufficient alignment between interface design and human cognition may generate new risks, including overreliance, distrust, reduced engagement, and out-of-the-loop performance problems (Balfe *et al.*, 2018; Papadimitriou *et al.*, 2020).

Human error in railway systems should therefore be interpreted as a systemic phenomenon rather than as an isolated individual failure. Errors frequently arise from the interplay among cognitive limitations, environmental complexity, organizational demands, and technological design. Fatigue may reduce vigilance, workload may narrow attention, automation may weaken active engagement, and poor interface transparency may distort mental models. In such conditions, deviations in perception, judgment, or reaction timing become predictable outcomes of system misalignment rather than exceptional events. This perspective shifts the analytical focus from blame to resilience, emphasizing the need to design railway systems that support cognitive stability under pressure.

The railway-focused literature also shows that the human factor is relevant not only in frontline operational contexts, but also in strategic and infrastructural decision-making. Multi-criteria decision-making models, expert-based safety assessments, disruption management procedures, and automation governance frameworks all rely on human expertise, value judgments, and interpretation of operational priorities. Consequently, the human factor is structurally embedded in railway safety at multiple levels: individual cognition, team coordination, human-machine interaction, organizational policy, and system-level governance.

Taken together, previous research supports a socio-technical interpretation of railway decision-making. Safe and efficient rail operations depend on the calibration between cognitive capacity, emotional regulation, workload demands, automation design, and institutional decision frameworks. Automation may improve operational performance, but it does not eliminate the need for human judgment; rather, it shifts the form and location of cognitive responsibility. Strengthening railway safety, therefore, requires human-centered design, fatigue and workload management, transparent automation interfaces, adaptive training, and decision-support systems that incorporate human reliability considerations.

2. METHODOLOGY

DESIGN

The study used a bibliometric and thematic review design to examine the structure of railway-specific research on the human factor in decision-making. Because the analysis was based exclusively on published scientific articles, the study did not involve human participants, experimental intervention, or primary data collection. The analytical sample consisted of a documentary corpus of peer-reviewed journal articles selected through a structured screening procedure.

DATABASE AND SEARCH STRATEGY

The bibliographic corpus was constructed using the Web of Science Core Collection as the sole indexing database. Web of Science was selected because it provides standardized, exportable bibliographic metadata that are suitable for VOSviewer analysis, including author information, source titles, publication years, keywords, categories, and digital object identifiers. Its controlled indexing structure also supported a reproducible search and screening process across transportation research, ergonomics, applied psychology, safety science, and operational research. At the same time, the exclusive reliance on Web of Science was a deliberate delimitation rather than a claim of exhaustive coverage. Relevant studies indexed only in Scopus, IEEE Xplore, ScienceDirect, Google Scholar, specialized transportation databases, or conference proceedings may not have been captured. Therefore, the corpus should be interpreted as a railway-specific Web of Science-based sample

designed for controlled bibliometric mapping, not as a complete census of all research on human factors in railway decision-making. The search strategy was designed to identify studies that explicitly connected railway environments with human factors, cognitive performance, decision-making, human reliability, situational awareness, or automation.

The following Boolean query was applied: (“railway” OR “rail transport” OR “train driver” OR “rail operations”) AND (“human factor” OR “decision making” OR “cognitive” OR “situation awareness” OR “human reliability” OR “automation”).

The search was restricted to peer-reviewed journal articles indexed between 2014 and 2024. Conference proceedings, editorials, book chapters, review-only materials, and early access articles beyond the 2024 cut-off were excluded. Subject-category filters were applied to preserve interdisciplinary relevance while maintaining railway specificity. Eligible Web of Science categories included Transportation, Applied Psychology, Neurosciences, Multidisciplinary Sciences, and Public Environmental Occupational Health, provided that the studies were directly connected to railway contexts.

INCLUSION AND EXCLUSION CRITERIA

Articles were included if they explicitly addressed human cognitive processes, decision-making, safety behavior, workload, situational awareness, human reliability, automation, or human–system interaction in railway operational contexts. Studies were excluded if they focused exclusively on infrastructure engineering, logistics optimization, economic modeling, or non-rail transport domains without a direct human-factors component. Publications were also excluded if their titles, abstracts, or keywords did not clearly relate to human decision-making or cognitive performance in railway environments.

CORPUS IDENTIFICATION AND SCREENING

The first Web of Science search yielded 2,733 records. Restricting the search to the 2014–2024 interval reduced the dataset to 1,875 records. Limiting the corpus to peer-reviewed journal articles resulted in 1,230 records. After subject-category filtering, 227 records remained. Title screening removed non-railway and infrastructure-only studies, producing a preliminary corpus of seventy-two articles.

Abstract and keyword screening then identified 27 articles that directly aligned with the railway-specific research objective. Because the intersection between railway decision-making, human reliability, cognitive-error analysis, and formal decision-support modeling remains insufficiently explored, two complementary methodological references from adjacent high-risk or decision-analytic domains were also retained for contextual interpretation. These references were not treated as railway-specific empirical evidence. They were not included in the railway-specific VOSviewer mapping: Ahmed *et al.* (2020) was used to contextualize multi-criteria prioritization under uncertainty, while Theophilus *et al.*

(2017) was used to illustrate structured cognitive-error analysis in another high-risk industry.

The final analytical material, therefore, consisted of twenty-seven railway-focused articles and two complementary methodological references. Because the railway-focused bibliometric corpus was small, the bibliometric results were interpreted as exploratory structural patterns rather than as statistically stable representations of the entire field.

The stepwise screening procedure, including the reduction from the initial Web of Science retrieval to the twenty-seven railway-focused articles included in the bibliometric mapping and the addition of two complementary methodological references used only for contextual interpretation, is summarized in Table 1.

Table 1

Search and screening summary		
Screening stage	Procedure applied	Records remaining
Initial database retrieval	Boolean search in Web of Science Core Collection	2,733
Time filter	Publications restricted to 2014–2024	1,875
Document type filter	Peer-reviewed journal articles only	1,230
Subject category filter	Transportation, Applied Psychology, Neurosciences, Multidisciplinary Sciences, Public Environmental Occupational Health	227
Title screening	Removal of non-railway and infrastructure-only studies	72
Abstract and keyword screening	Direct relevance to human decision-making in railway contexts	27
Complementary methodological contextualization	Adjacent high-risk or decision-analytic relevance to underexplored methodological aspects	2
Final analytical material	Railway-focused corpus plus complementary methodological references	29

BIBLIOMETRIC MAPPING PROCEDURE

Bibliographic metadata from the 27 railway-focused articles were exported in a standardized format, including authorship, publication year, source title, author keywords, index keywords, and digital object identifiers. The data were analyzed using VOSviewer to construct and visualize bibliometric networks. The two complementary methodological references were not included in the VOSviewer mapping. These references were excluded from all bibliometric calculations, keyword co-occurrence analyses, co-authorship analyses, and network visualizations. However, they were used only in the thematic discussion to contextualize the transfer of methods from adjacent high-risk or decision-analytic domains. Keyword

co-occurrence analysis was used to identify the observable conceptual structure of the selected corpus, while co-authorship analysis was used to examine collaboration patterns within the same corpus. Because of the dataset's limited size, the maps were used primarily as interpretive and exploratory tools rather than as evidence of definitive field-level boundaries.

Before analysis, keyword normalization was conducted to reduce artificial fragmentation in the co-occurrence map. Conceptually overlapping terms were harmonized where necessary, including singular and plural forms, spelling variants, hyphenated and non-hyphenated forms, and closely related expressions referring to the same construct. For example, variants related to decision making, human factors, automation, human reliability, workload, and situational awareness were reviewed for consistency while preserving railway-specific terminology. Cluster interpretation was not based solely on the automatic color assignment generated by VOSviewer. The clusters were interpreted by combining co-occurrence strength, node proximity, semantic coherence among keywords, and manual checking of titles, abstracts, and keywords in the retained articles. The bibliometric maps were therefore used as an empirical basis for thematic interpretation, while the discussion distinguishes between patterns emerging directly from the mapping exercise and broader theoretical interpretation.

DATA EXTRACTION FRAMEWORK

A structured data-extraction framework was developed to ensure consistency across the 27 railway-focused studies included in the bibliometric corpus. Each article was coded according to publication characteristics, railway context, methodological design, core human-factor constructs, decision-making relevance, safety-related outcomes, and reported implications. Attention was given to decision performance, human reliability, cognitive workload, situational awareness, automation, and operational safety. Information not explicitly reported in the original articles was coded as not reported to avoid unsupported inference. The standardized extraction matrix is provided in Appendix A.

3. RESULTS

KEYWORD CO-OCCURRENCE STRUCTURE

The keyword co-occurrence analysis suggested a coherent but exploratory conceptual structure organized around three thematic clusters. These clusters suggest that railway human-factors research in decision-making contexts is structured around interactions among formal decision-support approaches, operational human performance, and broader socio-technical system perspectives. Given the limited corpus size, the clusters should be read as indicative patterns within the selected Web of Science sample rather than as definitive boundaries of the field.

Figure 1 presents the keyword co-occurrence network generated from the 27 railway-focused articles using VOSviewer.

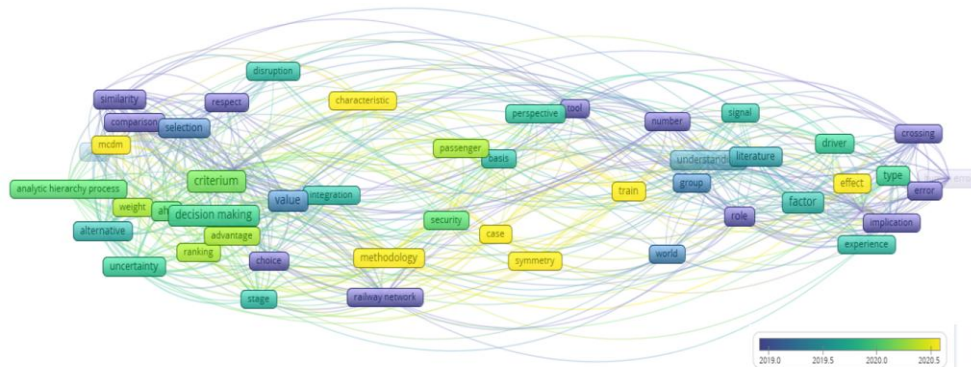


Figure 1. Keyword co-occurrence network of railway decision-making and human-factor research (VOSviewer visualization)

The first cluster is centered on decision support and multi-criteria modeling terminology, including concepts such as decision-making, analytic hierarchy process, MCDM, ranking, selection, weight, criterion, alternative, comparison, uncertainty, and railway network. This cluster appears to reflect a methodological research stream in which railway decisions are treated as structured evaluation problems under uncertainty. Within this domain, formal models function as analytical tools for comparing alternatives, prioritizing criteria, and supporting high-stakes operational or strategic decisions.

The second cluster is associated with operational human performance and safety. It includes terms such as human error, driver, experience, understanding, factor, automation, tool, signal, questionnaire, case, and railway level crossing. This cluster appears to reflect research concerned with cognitive performance, behavioral safety, human-system interaction, and the conditions under which railway operators make or fail to make reliable decisions. Its structure is consistent with the interpretation that human error is approached as an outcome of interactions among cognitive demands, system design, automation, and operational context, rather than as a purely individual failure.

The third cluster holds integrative and system-level terminology, including integration, perspective, security, passenger, world, basis, symmetry, and characteristic. This cluster situates railway decision-making within broader socio-technical and governance perspectives. It extends the analysis beyond frontline operators and points to systemic dimensions of railway safety, including infrastructure, organizational priorities, security, and passenger-related implications.

Taken together, the three clusters address RQ1 by suggesting that railway human-factor research in decision-making contexts is organized around three interconnected domains: formal decision analytics, operational cognitive performance, and socio-technical integration. Their proximity in the network is consistent with

the interpretation that effective railway decision-making depends on the alignment of analytical models, human cognitive capacities, automation design, and system-level governance.

CO-AUTHORSHIP NETWORK ANALYSIS

The co-authorship analysis identified five collaboration clusters within the selected corpus. Figure 2 presents the co-authorship network, showing that railway decision-making research is organized around several specialized yet interconnected research groups.

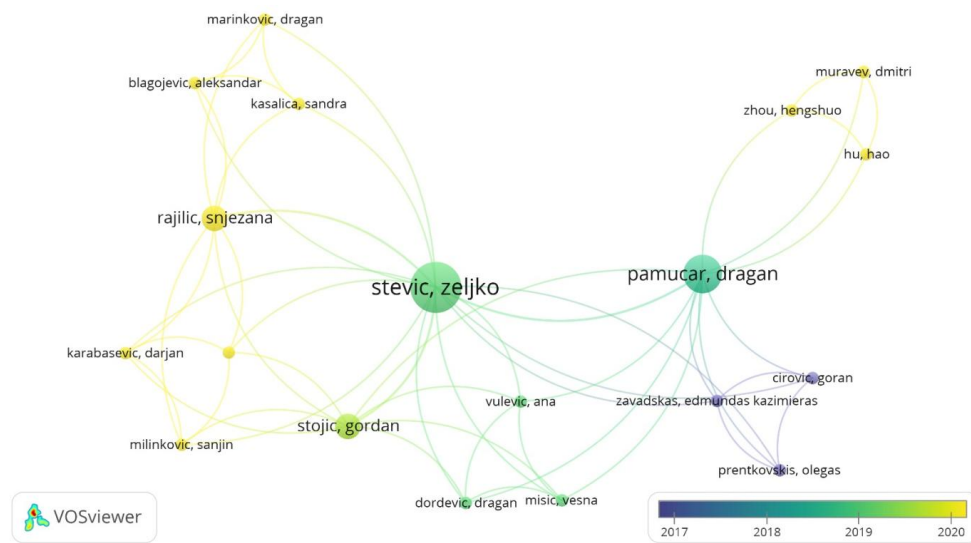


Figure 2. Co-authorship network of the railway decision-making research corpus (VOSviewer visualization)

The first cluster is centered on Željko Stević and collaborators, including Blagojević, Marinković, Kasalica, and Rajilić. This group is strongly associated with multi-criteria decision-making and railway safety evaluation.

The second cluster is structured around Dragan Pamucar and collaborators such as Muravev, Zhou, and Hu, reflecting work on optimization frameworks and decision-support architectures in transportation contexts. The connection between Pamucar and Stević indicates methodological exchange between related decision analytics communities.

The third cluster includes Đorđević, Mišić, Stojić, and Vulević, forming a secondary decision-modeling group, associated with service-quality criteria and structured decision models in rail transport (Dordevic *et al.*, 2019). The fourth cluster, including Čirović, Zavadskas, and Prentkovskis, reflects a broader European tradition in transport decision analytics and multi-criteria decision-making. The fifth cluster, composed of Karabasević, Milinković, and Vesko, represents a smaller

but cohesive collaborative unit with thematic proximity to fuzzy multi-criteria approaches applied to passenger-rail operator decision-making (Veskovic *et al.*, 2020).

Overall, the co-authorship structure addresses RQ2 by suggesting that, within the selected corpus, the strongest collaboration patterns are concentrated in decision-support and multi-criteria modeling communities. At the same time, the network is consistent with a relative separation between modeling-oriented authors and authors working primarily on operational cognition, fatigue, workload, automation monitoring, or human reliability. This pattern should be interpreted cautiously, because co-authorship maps indicate collaboration structures within the retained corpus but do not demonstrate disciplinary separation in the broader field. Nonetheless, the pattern suggests that the corpus exhibits stronger methodological integration in decision analytics than at the interface between formal modeling and empirical human-factors research.

SYNTHESIS OF STRUCTURAL GAPS

The combined interpretation of the keyword and co-authorship networks addresses RQ3 by suggesting a possible structural gap between strategic decision-support modeling and operational human reliability research. Within the selected corpus, multi-criteria and optimization models are prominent. However, they often focus on infrastructure, safety evaluation, service quality, risk prioritization, or transport planning rather than dynamic cognitive variables such as workload, fatigue, situational awareness, trust calibration, and operator resilience.

Conversely, studies centered on human performance provide important evidence on fatigue, cognitive workload, automation, and reliability, yet these constructs are not consistently incorporated into formal railway decision-support frameworks. This suggests a conceptual gap between models that support institutional or strategic decisions and empirical research explaining how operators perceive, interpret, and respond to railway system demands.

The results, therefore, support the recommendation that future railway safety research should integrate cognitive performance indicators into decision-support models more explicitly. Such integration would allow railway decision-making frameworks to account not only for technical and organizational criteria but also for human reliability, workload thresholds, automation transparency, and situational awareness. This would strengthen the socio-technical validity of railway safety models and support more human-centered automation governance.

4. DISCUSSION

The present study examined the structure of railway-specific research on the human factor in decision-making by integrating bibliometric mapping with thematic interpretation. The findings support the interpretation that the interaction between formal decision-support models, operational human performance, automation, and socio-technical governance shapes railway decision-making. This

interpretation is consistent with socio-technical systems theory and systems ergonomics, according to which safety depends on the alignment between human cognition, technological architecture, task demands, and organizational conditions rather than on technical reliability or procedural compliance alone (Carayon, 2006; Waterson *et al.*, 2015; Wilson, 2014).

The keyword co-occurrence analysis identified three interconnected domains: decision-support modeling, operational human performance, and socio-technical integration. The modeling-oriented cluster shows that railway research increasingly uses multi-criteria, fuzzy, optimization, and reliability-oriented frameworks to support infrastructure and rail-transit suitability assessment, logistics-center location, rolling-stock reliability and maintenance decisions, derailment risk assessment, service-quality evaluation, passenger-transport planning, and safety prioritization (Appoh *et al.*, 2021; Blagojević *et al.*, 2020; Caliskan & Atahan, 2023; Dordevic *et al.*, 2019; Muravev *et al.*, 2020; Stevic *et al.*, 2017; Stoilova, 2020; Stoilova & Munier, 2021; Veskovic *et al.*, 2020; Zhang & Sun, 2019, 2020). These approaches enhance analytical transparency and support structured decision-making under uncertainty. Comparable applications of multi-criteria decision-making outside the railway domain also show how expert-based weighting and prioritization can support complex decisions under uncertainty, although such approaches require adaptation to railway-specific safety and human-reliability criteria (Ahmed *et al.*, 2020). This comparison reinforces the methodological relevance of MCDM approaches without weakening the railway-specific focus of the present review. However, they remain dependent on expert judgment and value-based prioritization, indicating that the human factor is embedded not only in frontline operational decisions but also in strategic and institutional railway governance.

The operational cluster highlights the continued importance of cognitive performance, fatigue, workload, human error, situational awareness, level-crossing behavior, signal interpretation, and driver interaction with assistive technologies in railway safety (Filtneß & Naweed, 2017; Harrison *et al.*, 2022; Larue *et al.*, 2016, 2020, 2021; Lo *et al.*, 2016). Empirical research shows that fatigue and workload pressure can affect train driver reliability and operational performance (Filtneß & Naweed, 2017; Harrison *et al.*, 2022). Situational awareness and stable mental models also serve as key mechanisms by which operators interpret system states and adapt their decisions under dynamic conditions (Lo *et al.*, 2016). These findings reinforce the interpretation that human performance variability remains a central safety determinant, especially in contexts that require sustained attention, rapid interpretation, and adaptive response.

Automation represents a particularly important point of convergence between the modeling and operational domains. Although it may improve punctuality, energy efficiency, control precision, and system coordination, it does not remove human responsibility. Instead, it redistributes cognitive demands by requiring operators to supervise automated outputs, detect anomalies, calibrate trust, and intervene under uncertain conditions (Balfe *et al.*, 2018; Papadimitriou *et al.*,

2020). This interpretation is consistent with studies on intelligent control architectures, automatic train operation, and safety-oriented decision-making for electronic railway signaling systems, which suggest that technical sophistication must be accompanied by cognitive transparency and human-centered system design (Atanasov *et al.*, 2023; Pascale *et al.*, 2018; Wang *et al.*, 2022).

The integrative cluster indicates that railway decision-making can be understood as a socio-technical process shaped by operational disruption, organizational constraints, security demands, and systemic resilience. Research on disruption management, urban-rail disruption analysis, rail-station security, and post-crisis railway operations demonstrates that decision quality depends not only on individual cognition but also on institutional coordination, system flexibility, infrastructure vulnerability, security governance, and the capacity to respond to unexpected events (Kaewunruen *et al.*, 2018; Liu *et al.*, 2021; Schipper & Gerrits, 2018; Wang *et al.*, 2023). This perspective expands the role of the human factor beyond individual operators and situates it within broader governance, planning, and safety-management structures. It is also compatible with resilience engineering and Safety-II perspectives, which emphasize that safety is produced not only by preventing errors but also by enabling frontline adaptation, maintaining foresight about evolving risks, and supporting successful performance under variable conditions (Provan *et al.*, 2020).

A central contribution of the study is the identification of a potential structural gap between formal decision-support models and empirical human factors research. Multi-criteria decision-making approaches often include safety, efficiency, cost, infrastructure, maintenance, logistics, service-quality, planning, and risk-prioritization criteria (Appoh *et al.*, 2021; Caliskan & Atahan, 2023; Dordevic *et al.*, 2019; Muravev *et al.*, 2020; Stoilova & Munier, 2021; Veskovc *et al.*, 2020; Zhang & Sun, 2019, 2020). However, they rarely integrate dynamic cognitive indicators such as fatigue, workload thresholds, situational awareness, trust calibration, or resilience. Conversely, studies focused on human reliability and cognitive performance provide detailed insight into operator behavior, but these findings are not consistently translated into strategic railway decision-support models. Comparable work from other high-risk industries further indicates that structured techniques for analyzing cognitive errors can support retrospective and predictive safety assessment; however, such approaches require domain-specific adaptation before they can be transferred to railway decision-making contexts (Theophilus *et al.*, 2017). Bridging this gap would strengthen the ecological and socio-technical validity of railway safety models.

From a practical perspective, the results support the need for human-centered railway safety management. Fatigue management interventions, simulator-based training, automation interface design, and reliability-informed decision-support systems represent particularly relevant directions (Balfe *et al.*, 2018; Filtness & Naweed, 2017; Olsson *et al.*, 2023). Railway organizations could operationalize

this integration in several concrete ways. Fatigue and workload indicators may be incorporated into safety dashboards, roster planning, incident-review procedures, and risk matrices used for operational decision-making. Situational awareness and trust calibration can be addressed through simulator scenarios that expose train drivers and traffic controllers to automation failures, ambiguous signals, degraded-mode operations, and high-workload transitions. Human-machine interface audits can evaluate whether automated outputs are transparent, interpretable, and actionable under time pressure. Decision-support models can also include human reliability criteria alongside technical, economic, and infrastructural criteria, allowing safety managers to evaluate not only which option is technically optimal but also which option is cognitively sustainable for operators. Railway organizations should therefore treat human variability not only as a source of risk, but also as a potential resource for adaptive resilience when operators are supported by adequate workload regulation, transparent automation, and well-designed decision environments.

Several limitations must be acknowledged. First, the study relied exclusively on the Web of Science Core Collection to construct the corpus. Although this database provides standardized metadata and strong coverage of peer-reviewed research relevant to transportation, ergonomics, applied psychology, and safety science, the exclusive use of a single database may have limited the review's thematic breadth. Relevant publications indexed only in Scopus, PubMed, ScienceDirect, IEEE Xplore, Google Scholar, specialized transportation databases, or grey literature sources may therefore have been omitted. Second, the bibliometric corpus included only 27 railway-focused articles, complemented by two methodological references from adjacent high-risk or decision-analytic domains used for contextual interpretation. This number is appropriate for a tightly delimited railway-specific mapping exercise. However, it limits the stability of bibliometric patterns and makes the resulting clusters sensitive to database coverage, keyword availability, threshold choices, and VOSviewer parameter settings. Consequently, the 27-article bibliometric corpus should be interpreted as a railway-specific Web of Science-based corpus rather than as an exhaustive representation of the entire literature on human factors in railway decision-making. The prominence of modeling-oriented studies and specific co-authorship communities may also reflect database coverage and indexing patterns, which can influence the structure of bibliometric maps. Third, bibliometric analysis identifies conceptual and collaborative relationships, but it does not establish causal mechanisms or quantify the magnitude of empirical effects. Future research should expand the corpus across multiple databases and examine how cognitive performance indicators can be incorporated into formal railway decision-support frameworks.

Overall, the findings suggest that the human factor remains a structural determinant of railway decision-making across operational, technological, and institutional levels. As rail systems continue to evolve toward greater automation and digital integration, railway safety research must move beyond the separation

between technical modeling and human performance analysis. More integrated models are needed to connect cognitive reliability, automation transparency, workload regulation, and strategic decision-support within a coherent socio-technical framework.

5. CONCLUSIONS

This study examined the human factor in railway decision-making through a railway-specific bibliometric and thematic analysis of peer-reviewed research published between 2014 and 2024. By mapping keyword co-occurrence structures and co-authorship patterns, the study distinguished three main domains within the field: formal decision-support modeling, operational human performance, and socio-technical integration.

The findings suggest that human decision-making remains a structural determinant of railway safety and operational reliability. Situational awareness, fatigue, cognitive workload, trust calibration, and human reliability continue to shape performance in both conventional and automated railway environments. Automation modifies the role of human operators, but it does not eliminate the need for human judgment; instead, it transfers cognitive responsibility toward monitoring, interpretation, anomaly detection, and intervention.

The analysis also suggests that railway decision-making research extends beyond frontline operational contexts. Multi-criteria decision-making models and optimization frameworks are increasingly used in strategic railway planning, safety evaluation, risk prioritization, and service-quality assessment. However, these models remain only partially integrated with empirical evidence on cognitive performance and human reliability. This gap suggests the need for decision-support frameworks that more explicitly incorporate indicators of workload, fatigue, situational awareness, trust in automation, and resilience.

The study contributes to the literature by synthesizing dispersed railway-focused research into a coherent socio-technical interpretation of decision-making and by clarifying how the field can move from predominantly technical or organizational decision models toward models that explicitly include cognitive and human-reliability indicators. Its findings support the development of human-centered railway safety models that connect cognitive performance, automation transparency, organizational governance, and formal decision analytics. Future research should expand the corpus across multiple databases and examine how operational human-factor indicators can be translated into strategic modeling tools for railway safety management.

In conclusion, technological advancement does not reduce the relevance of the human factor in rail transport. Safe and resilient railway operations depend on the alignment between human cognition, system design, automation architecture, and institutional decision processes. Strengthening this alignment should remain a central priority for railway safety research and practice.

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Appendix A. Standardized data extraction framework

The bibliometric corpus included twenty-seven peer-reviewed railway-focused articles selected through the screening procedure described in the Methodology section. Two additional methodological references from adjacent high-risk or decision-analytic domains were retained only for contextual interpretation and were not included in the VOSviewer mapping. To ensure consistency across studies, each article was coded using a standardized extraction framework. The framework was designed to capture the bibliographic, methodological, cognitive, and safety-related characteristics relevant to railway decision-making and human-factor research.

Table A1

Data extraction framework applied to the final corpus

Extraction domain	Coding category	Description
Bibliographic information	Author(s), year, journal, DOI	Identified the source, publication year, journal outlet, and digital object identifier.
Railway context	Operational domain	Coded whether the study addressed train driving, traffic control, passenger transport, railway level crossings, signaling, rolling stock, infrastructure, automation, or strategic planning.
Study orientation	Empirical, modeling, methodological, or system-level	Classified the main research orientation of each article.
Methodological approach	Quantitative, qualitative, mixed, simulation-based, bibliometric, or multi-criteria modeling	Captured the main analytical procedure used in the study.
Human-factor construct	Fatigue, workload, situational awareness, trust, human reliability, cognitive performance, human error, or behavioral safety	Identified the central human-factor variable or concept.
Decision-making relevance	Operational, tactical, strategic, or governance-related	Coded the level at which decision-making was addressed.
Automation relevance	Direct, indirect, or not reported	Indicated whether automation, intelligent systems, or supervisory control were central to the study.
Safety outcome	Reliability, risk, error, disruption, resilience, safety performance, or service quality	Captured the main safety- or performance-related outcome.
Main contribution	Conceptual, empirical, methodological, or practical	Summarized the principal contribution of the article to railway human-factor research.
Reported limitation	Present or not reported	Coded limitations explicitly stated by the authors.

The extraction framework enabled comparison across heterogeneous studies while preserving the distinction between operational human-factors research and formal decision-support modeling. Variables that were not explicitly reported in the original articles were coded as not reported to avoid unsupported inference. The resulting matrix informed the interpretation of the keyword co-occurrence clusters, the co-authorship network, and the structural gap between modeling-oriented and human reliability-oriented research streams.