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An Analysis of Accidents Caused by Human Error among Railway Trackside Workers*

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Abstract

Purpose: This study systematically analyzes the characteristics of human error accidents among railway trackside workers to identify dominant patterns and propose safety management strategies. **Research design, data and methodology:** This quantitative study analyzed 10 years (2012-2021) of KORAIL accident records. Incidents were classified using the Human Error Analysis and Reduction (HEAR) framework. The analysis primarily involved descriptive statistics to examine the distribution of error types, causes, and outcomes, with a supplementary job analysis. **Results:** The analysis revealed that incidents in the Facilities sector were twice as frequent as in the Electrical sector. The most prevalent error type was Decision-Making Error (56.9%), showing accidents primarily stem from flawed judgments and procedural violations rather than simple execution slips. Worker injury was the most common outcome, and accidents were concentrated in specific high-risk tasks like turnout maintenance and signal equipment inspection. **Conclusions:** This study concludes that human errors in trackside operations are systemic issues rooted in decision-making and procedural compliance. The findings support multi-faceted countermeasures, including enhanced scenario-based training, adopting advanced safety technologies to reduce cognitive load, improving fatigue management through scheduling, and robust safety feedback systems.

Keywords : Human Error, Railway Safety, HEAR Methodology, Trackside Workers

JEL Classification Code: J28, L92, R41

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1. Introduction

1.1. Research Background

Human error is defined as a phenomenon that increases the risk of accidents or directly causes them, stemming from mistakes, omissions, and rule violations in the human processes of cognition, judgment, and execution (Reason, 1990). While accidents attributable to mechanical and environmental factors have seen a long-term decline with technological advancements, the contribution of human error remains significant. This is because the growing complexity of systems and the increasing volume of information elevate the cognitive load on workers. In this context, modern industrial safety has shifted its focus from merely asking, “what went wrong?” (Safety-I) to also understanding “how things go right” (Safety-II), thereby making the prevention of human error and the enhancement of resilience a top priority (Hollnagel, 2014).

As a primary mode of mass public transit, the railway is a highly interconnected system where conventional, urban, and high-speed rail lines operate in an integrated manner. The complex operational framework and the necessity for real-time information exchange and coordination demand a high level of situational awareness and team-based communication from trackside workers. In connection with this, domestic studies have repeatedly indicated that human errors occurring in these processes significantly affect safety performance metrics (Yum, 2024). In particular, maintenance work on active lines within the Facilities sector (e.g., civil, signal, and power systems) is characterized by substantial process interference, stringent time constraints, and high interface complexity involving trains, equipment, and control centers. These factors elevate the risk of technical failures combining with human factors to escalate into major accidents. Therefore, managing human error in the railway Facilities sector requires a systematic approach that extends beyond individual faults to encompass latent failures at the organizational, procedural, and supervisory levels (Shappell & Wiegmann, 2000; Lee et al., 2013).

A pertinent real-world example is the major accident that occurred at Guro Station in Seoul in 2024, where a collision between two electric motorcars used for track inspection and maintenance during early morning hours resulted in the death of two Korea Railroad Corporation (KORAIL) employees and injury to another. According to initial reports, the incident involved one maintenance motorcar colliding with a track inspection train, with preliminary findings suggesting the possibility of combined failures in work authorization, information exchange, and mutual confirmation. This case illustrates that implicit assumptions in situational assessment and communication among workers can lead to fatal outcomes in high-risk operational contexts. The incident reaffirms the critical importance of preliminary risk assessments, adherence to work limits (e.g., clearance limits and track possession zones), robust communication between the control center and field staff, and the strict observance and supervision of check-back procedures in trackside operations.

Therefore, this study aims to systematically analyze human error-related accidents involving trackside workers in the Facilities sector to identify precursors and propose preventative measures for mitigation and preparedness. Methodologically, this research will utilize the Human Error Analysis and Reduction (HEAR) framework, a specialized method for analyzing human error characteristics in the railway industry. Within this framework, a multi-layered causal network will be derived by classifying error types, accident outcomes, and contributing factors.

2. Literature Review

Human error refers to incorrect human decisions or actions that occur in situations where diminished work-processing capacity or impaired efficiency leads to safety accidents. Such errors can result in repetitive mistakes and may affect the safety of human-machine systems depending on the level of job satisfaction. Research by the Aviation and Railway Accident Investigation Board has identified causes of human error in railway accidents, including misperformance, inattention, operational errors, and rule violations. These are interpreted as stemming from complex and diverse origins associated with individual worker limitations as well as organizational and operational factors.

2.1. Theoretical Background

2.1.1. The System Approach to Human Error (Reason, 1990)

Reason (1990) proposed that human error should be understood not from a ‘person approach’ but from a ‘system approach.’ He explained that errors—such as slips, lapses, mistakes, and violations—occur as by-products of normal cognitive mechanisms. An accident manifests when latent conditions (i.e., hidden flaws) existing within an organization's various defensive layers (e.g., policies, procedures, training, and supervision) align with unsafe acts on the front line. The core principle is to move beyond blaming individuals and instead focus on reducing the potential for error through improved organizational, procedural, and environmental design. This involves creating multi-layered defenses (e.g., approvals, cross-checks, interfaces that support situational awareness, and audit systems) to ensure that even if an error occurs, it does not escalate into an accident.

2.1.2. The Seven Stages of Action (Norman, 2013)

Norman (2013) explains human-system interaction using his Seven Stages of Action model, which consists of goal formation → execution (planning, specifying, performing) → and evaluation (perceiving, interpreting, comparing). He proposed points for design improvement by distinguishing between slips/lapses, where the plan was appropriate but the execution was flawed (e.g., a memory lapse), and mistakes, where the plan itself was inappropriate (either rule-based or knowledge-based). This suggests that issues in railway Facilities work, such as mode errors (confusion regarding equipment operating modes), misoperations due to description similarity, and checklist omissions, can be prevented through design that considers slips and lapses (e.g., improving visibility, feedback, affordances, and constraints). Conversely, errors in selecting procedures or rules can be mitigated by clarifying rules and providing decision support. This framework provides the design principle: "Make errors difficult by changing the interface and procedures, rather than by trying to change the person."

2.1.3. HFACS (Shappell & Wiegmann, 2000)

The Human Factors Analysis and Classification System (HFACS), which evolved from aviation accident analysis, is a multi-layered framework for classifying human factors. It identifies and codes causes across four hierarchical levels: (1) Unsafe Acts (errors and violations), (2) Preconditions for Unsafe Acts (e.g., fatigue, teamwork, communication, environment), (3) Unsafe Supervision, and (4) Organizational Influences. Its strengths lie in analyzing large datasets and prioritizing countermeasures for preventing recurrence. The framework structurally reveals the interconnected problems between the organization, supervision, and frontline operations, such as procedural violations, lack of authorization, and flawed information sharing.

2.1.4. HEAR (Kim et al., 2009)

HEAR (Human Error Analysis for Railway) is a specialized analysis framework tailored for accident and incident investigations within the Korean railway domain. It standardizes a seven-step procedure: (1) event definition, (2) identification of unsafe acts, (3) classification of error types (including slips, lapses, mistakes [rule-based/knowledge-based], and violations), (4) elicitation of contextual Performance Shaping Factors (PSFs), (5) tracing the multi-layered causal network using a Why–Because Tree, (6) assessment of severity and recurrence probability, and (7) mapping of countermeasures.

Based on this framework, researchers developed CAS-HEAR, a computer-aided analysis system. In an evaluation by nine field investigators, CAS-HEAR demonstrated that it could enhance the quality and consistency of analysis. Notably, by using pre-defined links between causal factors, the system was able to detect approximately 96% of the actual causes documented in accident reports, thereby improving the efficiency metric of ‘selectivity.’ Domestic studies applying HEAR have presented case studies, classification systems, and codebooks. These studies identify role-specific PSFs—such as procedural adequacy, time availability, training, communication, and authorization systems—as key axes for improvement across different functions like Facilities, signaling, and control

2.2. Previous Studies

2.2.1. Proposal of SMaSHE (Kim et al., 2008)

Kim et al. (2008) reanalyzed disaster and accident data from highway construction sites from an ergonomics perspective. They structured human errors—often vaguely dismissed in the field as ‘carelessness’—into six categories based on an information processing model. Building on this, they proposed SMaSHE(Safety Management System based on Human Error for Construction Sites), a worker-centric safety management framework rooted in cognitive psychology. SMaSHE was designed to supplement the limitations of existing facility-centric and reactive safety management by integrating process segmentation with a knowledge-based DB, maximization of safety managers' cognitive capabilities, psychological motivation, and the alignment of administrative regulations with operational processes. The authors emphasized that for successful implementation, parallel efforts in revising laws and institutions, conducting education and workshops, and developing practical field application tools are necessary.

2.2.2. Analysis and Improvement of Track Worker Human Error (Kim et al., 2024)

Kim et al. (2024), using accident reports from KORAIL's Safety Management System (2013–2022), classified and analyzed casualty accidents involving track workers. After deriving causes using HFACS and Root Cause Analysis (RCA), the study systemized 14 preventative and 10 mitigative countermeasures using the Bow-Tie method. Key findings revealed that accidents were concentrated from July to September and occurred frequently during rail/crossing replacements, track maintenance, and patrol inspections. The HFACS analysis showed that errors (slips/lapses) (35%) and violations (32%) were prominent. This highlighted the need to improve organizational and procedural factors, such as the reliance on conventions and assumptions among skilled workers, safety complacency, and inadequate management.

2.2.3. Human Error Cause Analysis in Railway Accident Investigation Risk Analysis (Kim, 2018)

Kim (2018) applied a risk assessment-based analysis and the HEAR (Human Error Analysis for Railway) framework to several major domestic railway accidents (Daegu Station collision, Sangwangsimni Line 2 collision, and KTX Gwangmyeong derailment). The HEAR framework uses a Why-Because Tree to trace causes from the direct cause (unsafe act) back to 1st, 2nd, and 3rd-level background causes (individual; job/environmental; and organizational) to derive core root causes. It then proposes axes for improvement, such as Non-Technical Skills (NTS), qualifications/competencies, and organizational values. The study confirmed the advantage of HEAR's formalized methodology and procedures (e.g., causal models, decision-making models, and root cause evaluation), which enhance the consistency of investigations and improvement measures.

3. Research Methods and Materials

This study systematically reviewed 4,112 accident and incident records from the KORAIL covering a ten-year period (2012 – 2021) to analyze the characteristics of incidents caused by human error among railway trackside workers. Among all recorded events, only those cases in which human factors of railway employees were clearly identified as the direct cause were initially screened. From this subset, incidents directly related to track and facilities work performed on active railway lines—such as patrol inspections, track maintenance and replacement, and the operation or positioning of motorcars and other work equipment—were re-extracted, resulting in 204 final cases for detailed analysis.

All human-error-related events were included regardless of the scale of damage or their official classification under KORAIL regulations (e.g., dangerous occurrences, accidents, or incidents). This comprehensive inclusion of minor accidents and near-miss cases followed Heinrich's Law, which suggests that recurrent small-scale events can escalate into major accidents; thus, their examination supports the identification of fundamental root causes.

To enhance contextual understanding of human errors by trackside workers, a job analysis was performed. This process involved a review of relevant regulations, work manuals, and Standard Operating Procedures (SOPs), complemented by consultations with field practitioners to identify core tasks, required competencies, and risk-exposure points for each occupational category. The findings from the job analysis were used as qualitative references to interpret the quantitative results (i.e., the distribution of error types, causes, and outcomes).

The key variable, error type, was classified using the HEAR (Human Error Analysis and Reduction) framework with operational definitions adapted for this study: (1) Execution Error – a problem occurring during the implementation of a previously made decision; (2) Decision-Making Error – a failure to make a timely and appropriate decision in a given situation; (3) Situational Assessment Error – a failure to accurately assess a situation in time; and (4) Information Perception Error – a failure to perceive the information required for situational assessment.

Accident causes were coded into nine categories reflecting trackside-work characteristics and informed by prior research (Joo, 2014): Improper Equipment Handling, Improper Handling of Track Switches, Improper Signal Handling, Negligence in Signal Confirmation, Improper Operating Procedures, Negligence in Operational Coordination, Negligence in Preventing Unintended Vehicle Movement, Negligence in Maintenance, and Improper Work Procedures. Physical-handling or operational problems were coded under "Improper Handling/Procedure"; perception or interpretation failures were coded as "Negligence in Signal Confirmation"; non-compliance with safety procedures—such as work permits, track possession, protection, and risk assessment—was classified as "Improper Work Procedures"; and insufficient preventive maintenance of equipment was coded as "Negligence in Maintenance."

Accident outcomes were classified into 15 types according to their final consequences: Power Supply Failure, Track Switch Malfunction, Signal Malfunction, Emergency Train Stop, Train Service Disruption, Train Service Suspension, Incorrect Train Routing, Damage to Track Switch, Passenger Injury, Train Collision, Train Derailment, Damage to Train, Worker Injury, Worker Fatality, and Damage to Power Lines. In cases involving multiple outcomes, the most severe consequence—typically a worker injury or fatality—was prioritized and recorded as the primary outcome variable, while secondary effects were qualitatively described. This rule was applied consistently to ensure comparability across cases.

Data analysis relied primarily on descriptive statistics. The number and proportion of incidents were compared between the Facilities and Electrical sectors to identify dominant trends across error types, causes, and outcomes. Subsequently, associations between frequently occurring error types and their critical consequences (e.g., collisions, derailments, human casualties, emergency stops, or service suspensions) were examined and narratively summarized.

Through this procedure, the study stratified human-error incidents by sector (Facilities/Electrical) and, using descriptive statistics, presented the interrelationships among HEAR-based error types, causes, and outcomes. This approach enabled identification of recurring patterns and underlying root causes within the full spectrum of events—including minor incidents—and facilitated the derivation of priority management areas for enhancing safety in active railway-line operations.

4. Results

Figure 1 shows the number of human error incidents classified by sector over the ten-year period from 2012 to 2021. A comparison between the Facilities sector (responsible for construction and civil engineering) and the Electrical sector (responsible for signaling and electrical systems) reveals that incidents in the Facilities sector were approximately twice as frequent as those in the Electrical sector. This suggests that even within the shared context of working on active railway lines, tasks such as track maintenance and replacement, as well as the operation of motorcars and other work equipment, carry a higher inherent risk of accidents.

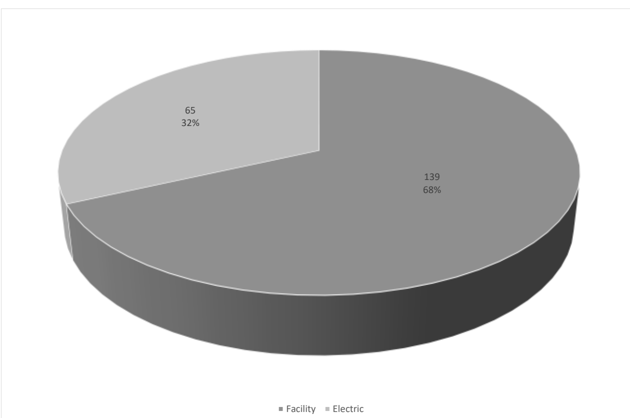

Figure 1: Human Error Incidents by Sector

Figure 2 presents the classification of human error incidents based on the HEAR framework. The figure details the proportion of each error type within the Facilities and Electrical sectors, with the numbers on the graph indicating the raw count of incidents for each category. The distribution of error types was found to be similar across both sectors.

Overall, for all trackside workers combined, the most frequent error type was Decision-Making Error (56.9%), followed by Situational Assessment Error (27.0%), Execution Error (12.3%), and Information Perception Error (3.9%). This indicates that a significant portion of human errors among trackside workers stems from flawed or incomplete decision-making, a category that encompasses all violations of procedures or regulations, regardless of intent. Furthermore, the relatively low proportions of Execution and Information Perception errors suggest that accidents are more likely to originate from an individual worker's judgment and actions rather than from failures in communication between workers.

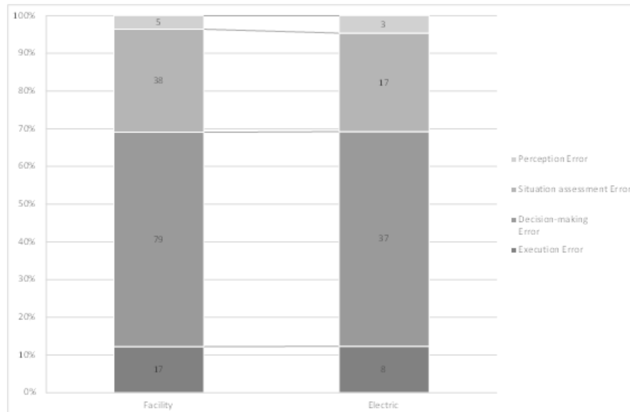

Figure 2: HEAR Error Types by Sector

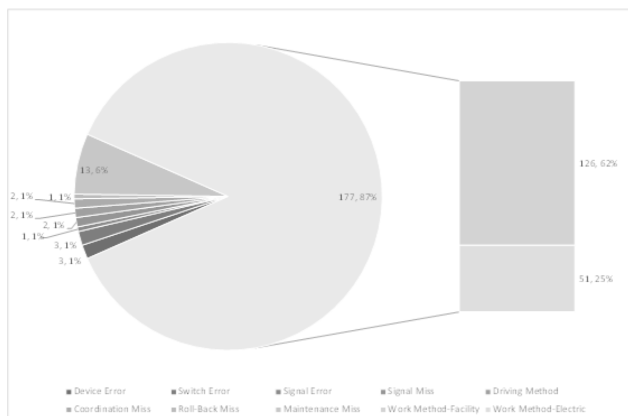

Figure 3: Incidents Causes

Table 1 presents the analysis of incidents classified by their final outcome. In both the Facilities and Electrical sectors, worker injuries constituted the most frequent outcome. Furthermore, when the events were categorized into two groups—actual accidents resulting in property damage or casualties, and near misses that only caused operational disruptions—the majority of human error-related events fell into the former category. This indicates that human error among trackside workers poses a significant threat to railway safety. Consequently, it is estimated that preventing such errors holds substantial utility in averting major accident-related damages.

Table 1: Outcomes by Type and Sector

Results of Incidents	Facility	Electric	Summary
Power Supply Failure	4	7	11
Switch Malfunction	4	1	5
Signal Failure	2	8	10
Emergency Stop	0	2	2
Train Operation Fault	8	2	10
Train Operation Halt	1	0	1
Wrong Route Entry	1	1	2
Switch Damage	0	3	3
Passenger Injury	1	0	1
Train Collision	2	0	2
Train Derailment	5	0	5
Train Damage	2	0	2
Worker Injury	102	36	138
Worker Fatality	1	0	1
Cable Damage	6	5	11

Table 2 provides a description of high-frequency incident-related job tasks, based on job analysis and quantitative analysis. In both the Facilities and Electrical sectors, maintenance and inspection-oriented field tasks showed a high frequency of incidents.

First, in the Facilities sector, the job tasks with the highest incident frequencies were 'Turnout Maintenance' (13 cases, 9.4%), 'PC Sleeper/Tie Replacement' (5 cases, 3.6%), and 'Track Surface & Line Alignment' (4 cases, 2.9%). Combined, these top three job tasks accounted for 15.9% of all incidents in this sector. These tasks commonly involve working in close proximity to the track, handling heavy materials, and process interference, leading to high-risk exposure. They are also characterized by detailed work stages and frequent coordination, which can easily lead to an accumulation of on-site operational risks.

Meanwhile, in the Electrical (EW) sector, the top high-risk job tasks were identified as 'Signal Equipment Patrol Inspection' (6 cases, 9.2%), 'Visual Inspection of Catenary' (5 cases, 7.7%), and 'Inspection using a Ladder Truck/AWP' (4 cases, 6.2%). Combined, these top three tasks accounted for 23.1% of all incidents in the Electrical sector. These tasks typically involve working at heights near or on energized lines and accessing equipment during maintenance, which entails a relatively high risk of immediate safety accidents such as electric shock, falls, and contact injuries.

Table 2: High Frequency Tasks by Sector

Sector	Major Job Task		No. of Incidents	Rate (%)
	Mid level	Sub classification		
Facility	Turnout Maintenance	Track Gauge Adjustment	13	9.4
	Track Material Renewal	Sleeper/Tie Replacement	5	3.6
	Track Maintenance Work	Track Surface & Line Alignment	4	2.9
Electric	Signal Control Equipment Inspection	Signal Equipment Patrol Inspection	6	9.2
	Track Patrol Inspection	Visual Inspection of Catenary	5	7.7
	Electric Railway Equipment Inspection	Inspection using Ladder Truck	4	6.2

To summarize, a pattern was derived in which accidents are relatively concentrated in track maintenance and alignment-related tasks for the Facilities sector, and in inspection and maintenance tasks for electric and signal equipment for the Electrical sector. Accordingly, it is valid for priority management to focus on strengthening compliance with standard procedures before, during, and after work, reducing risk exposure (blocking, separation, access control), and enhancing the effectiveness of on-site management and supervision for turnout, sleeper, and alignment tasks in the Facilities sector, and for catenary and signal equipment inspection / ladder truck utilization tasks in the Electrical sector.

5. Discussion

As a result of this study, it was confirmed that human error accidents of railway trackside workers are mostly caused by the worker's inappropriate decision-making and non-compliance with regulations (improper work procedures). Specifically, accident occurrence in the Facilities sector was about 2 times higher than in the Electrical sector, and in terms of error types, decision-making errors accounted for more than half (56.9%), showing a much higher proportion than situational assessment errors (27.0%). On the other hand, the proportion of execution errors or information perception errors appeared low at around 15%. This suggests that the main cause leading to accidents at railway work sites lies in misjudging the situation or failing to properly follow rules and procedures, rather than in simple operational mistakes. This tendency can be interpreted, when viewed through Norman's error theory, as meaning that mistakes in the goal-setting and judgment stage are more prominent than slips in the execution stage. In other words, it appears that the possibility of an accident is greater from a worker misperceiving the situation or selecting an inappropriate countermeasure, rather than from momentarily mishandling machinery.

The findings, centered on the analysis results, are largely in the same context as previous studies. In the track worker accident analysis by Kim et al. (2024), 36% of all accidents were errors (mistakes) and 31% were classified as regulation violations, and it was reported that worker's judgment errors or rule deviations were the main causes. This is a finding that corresponds with the fact that decision-making errors and situational assessment errors occupied the majority in this study. In particular, Kim et al. pointed out that both the judgment errors of inexperienced workers and the procedural violations of experienced workers are leading to accidents, and this shows that even with much experience in the field, there is a risk of ignoring safety rules or making arbitrary judgments. Also, in that study, along with the physical factors of the track and work environment, workers' lack of safety awareness and inadequate safety management were pointed out as major root causes. This means that for accident prevention, not only the improvement of individual attention but also organizational-level management improvement is essential. In fact, according to Reason's theory, it is said that an accident occurs not because of a single human fault, but when defects inherent throughout the organization penetrate and align through multiple defense layers, and this can share the same context with the fact that it is the foundation of human factors analysis techniques such as HFACS in the railway field.

The results of this study also show that supplementing systemic loopholes such as work authorization procedures and education/supervision systems is important, and reaffirms the necessity of the perspective of perceiving human error as an organizational error beyond a problem at the individual level. Meanwhile, although railway work is conducted on a team basis composed of controllers, drivers, and workers, in the statistics reviewed earlier, the individual worker's judgment errors are prominent, and errors in information delivery or collaboration appear low on the surface. This could easily be interpreted as "communication problems in the field are not significant," but on the other hand, it could be evidence of the field's implicit communication practices. In other words, there is a possibility that workers have been proceeding with work relying on experience and tacit understanding, rather than on official cross-checks or strict communication procedures. In such a culture, although it seems there are no problems usually, if the situation develops exceptionally or becomes urgent, the risk of a fatal error occurring is high in the part where official procedures were skipped.

The risk according to this assumption is also revealed in actual accident cases. The early morning electric motorcar collision accident that occurred at Guro Station in Seoul in August 2024 was an incident in which 2 workers died and 1 was seriously injured as a work platform encroached onto an adjacent track and collided with a track inspection train in operation. As a result of the investigation, it was confirmed that work was performed with the upper work platform of the railway work vehicle in a state that exceeded the approved work limits, and due to this, it collided with a train on the adjacent track, leading to a major accident. In that case, non-compliance with work authorization procedures and a lack of communication between the field and control were complexly pointed out, and this clearly shows that basic rules such as regulation compliance and check-backs are directly connected to life. In the end, this accident pointedly suggests that small violations or omissions that were taken for granted in normal times can bring about irreversible consequences in a dangerous work context.

Also, in this study, by cross-analyzing the HEAR classification and job analysis, the pattern of accidents being concentrated in specific jobs was confirmed. For Facilities, accidents occurred relatively frequently in the track maintenance series such as track gauge adjustment (13 cases, 9.4%), sleeper/tie replacement (5 cases, 3.6%), and track surface & line alignment (4 cases, 2.9%), and for Electrical, in signal equipment patrol inspection (6 cases, 9.2%), visual inspection of catenary (5 cases, 7.7%), and inspection using a ladder truck (4 cases, 6.2%). The combined proportion of the top 3 jobs was 15.9% for Facilities and 23.1% for Electrical, and a meaningful reduction effect can be expected with only the targeted management of a few key jobs. In the comparison between sectors, the fact that Facilities accidents are at a level about 2 times that of Electrical is interpreted as a reflection of the work characteristics of direct handling of tracks and materials and large process interference.

Several limitations also exist in this study. First, due to the limitation of the data scope, caution is needed in the generalization of the analysis results. This study relied on the accident and incident records of the KORAIL, so unreported incidents were not reflected. Therefore, in order to represent the trend of the entire railway industry, the encouragement and maintenance of the near-miss reporting system needs to precede. Also, due to the characteristic of being a secondary data analysis based on reports, there is a possibility that potential causes that were not revealed or reported during the on-site investigation process (e.g., poor management supervision, lack of prior proficiency of workers, etc.) were not sufficiently reflected in the classified cause categories. Also in terms of analysis techniques, this study mainly focused on descriptive statistics and deriving classification networks, so the causal relationships or correlations between each factor were not quantitatively identified. These parts have room to be supplemented through future in-depth statistical analysis or modeling techniques. Nevertheless, this study has significance in the point that it, based on data accumulated over the last 10 years, revealed the dominant error patterns of the railway trackside work site and presented priority areas of safety management for this. This provides academic and practical contributions in the point that it allows railway safety field workers and managers to recognize what types of mistakes occur frequently and can lead to major accidents, and that it can be used as base data for establishing preventive measures.

6. Conclusions

This study systematically analyzed the characteristics of human error accidents that occur at railway trackside work sites, and based on this, derived implications for improving safety management. As a result of applying the HEAR classification system to railway accident and incident data from 2012 to 2021, non-compliance with procedures due to the worker's wrong decision-making or judgment appeared as the cause of most accidents, and due to these errors, serious consequences such as worker injuries and train service disruptions were being caused. This suggests that in securing railway safety, the prevention of human error of on-site workers is a top priority task, and shows that not only arousing individual attention but also organizational-level support and management must be paralleled.

Based on the analysis results above, the following multi-faceted countermeasures are proposed to prevent human error of railway trackside workers. First, the strengthening of education and training for on-site workers must precede. It is necessary to improve workers' risk perception ability and response competency through realistic safety education programs and scenario-based training. For example, conduct emergency response practice in situations similar to the actual operating environment with simulation training utilizing simulators, and regularize case education that takes lessons from past accident cases. Through this, it is made so that workers can learn the importance of procedures through experience and can make correct decisions according to regulations even in urgent situations. In addition, by paralleling campaigns and education to establish a safety culture, an atmosphere where complying with rules in the field is taken for granted must be created.

Second, the introduction of advanced safety technologies that can reduce the worker's cognitive load and compensate for mistakes must be expanded. For example, devices are utilized that, through train approach warning devices or automatic protection systems, give a warning to the worker upon train approach and automatically stop the work. Also, by using smart sensors and communication technology, the worker's location and surrounding train operation information are monitored in real-time, and it can be made so that an immediate alarm sounds if the work limit zone is crossed or a risk is detected. These technologies can supplement the limits of the worker's attention and can contribute to preventing accidents due to human error in advance.

Third, to reduce fatigue accumulation due to long work hours and shift work, manpower operation and work schedules must be improved. For example, the worker's fatigue can be managed by sufficiently guaranteeing rest time between shifts and by extending the rest interval after night work until the next shift. At the same time, the two-person-one-team work principle is thoroughly applied, and for dangerous work, a supervisor or additional manpower is dispatched so they cross-check each other. Along with this, it is supported so that workers can work in a safe environment by fully equipping safety devices and protective gear at the work site, and by mandating a pre-inspection of risk factors before work starts (e.g., toolbox meetings). Furthermore, by strengthening organizational-level safety management, efforts are also necessary where managers listen to difficulties in the field and raise the motivation for workers' safety. This is because the improvement of a worker's job satisfaction and psychological stability consequentially leads to safe work performance.

Fourth, through the systematic collection and analysis of accident data, the occurrence trend of human error must be monitored and a feedback system must be established. By creating a database of minor mistakes or near-miss cases that occur at railway work sites, the precursors to errors can be identified, and by analyzing this, high-risk work processes or conditions can be identified. Furthermore, technologies that predict and diagnose risk levels by collecting and analyzing the worker's biological signals, fatigue level, and behavior patterns in real-time by utilizing IoT sensors can also be considered. These technologies can be realized through measures such as developing a system that analyzes the worker's heart rate changes or movement patterns with AI to warn early of signs of decreased attention and makes managers intervene immediately. Also, when an accident occurs, the cause and response measures must be shared company-wide and used as educational material, to build a learning organizational culture so that the same type of error does not recur.

In future research, the interactions between the factors identified in this study and contextual factors need to be analyzed more in-depth. For example, by statistically verifying how the human error occurrence rate changes depending on specific environments (night work, bad weather, etc.) or organizational culture (level of safety climate), customized countermeasures for high-risk situations will be able to be prepared. Also, it is necessary to discover unreported minor human errors by activating the near-miss reporting system. Efforts are needed not to focus on simply punishing the causal agent of an incident, but to unearth the human factors that contain the risk of accidents, and through this, prepare countermeasures for regulations that are realistically difficult to apply in the field or for the causes that induce errors and mistakes, and to fundamentally manage and prevent human error. From a Safety-II perspective, efforts to build a human factors management system that also encompasses the factors of successful daily work are also important. Through such follow-up research and practice, it is expected that it will be possible to dramatically reduce human error at railway trackside work sites and furthermore contribute to improving the safety resilience of the entire railway system.

References

Dorrian, J., Baulk, S. D., & Dawson, D. (2007). Train driving efficiency and safety: Examining the cost of fatigue. *Accident Analysis & Prevention, 39*(3), 579–587. https://doi.org/10.1016/j.aap.2006.09.005

Dorrian, J., Baulk, S. D., & Dawson, D. (2011). Work hours, workload, sleep and fatigue in Australian rail industry employees. *Applied Ergonomics, 42*(2), 202–209. https://doi.org/10.1016/j.apergo.2010.06.009

Dorrian, J., Roach, G. D., Kozlovskiy, I., Grant, C. L., Lack, L., & Dawson, D. (2022). A survey of train driver schedules, sleep, wellbeing, and fatigue. *Scientific Reports, 12*, 3837. https://doi.org/10.1038/s41598-022-07961-y

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*(1), 32–64. https://doi.org/10.1518/001872095779049543

Hollnagel, E. (2014). *Safety-I and Safety-II: The past and future of safety management.* CRC Press. https://doi.org/10.1201/9781315607511

Kim, D. S., Baek, D. H., Yoo, S. Y., & Yoon, W. C. (2009). Development of a railway human error analysis methodology. *Proceedings of the Korean Society for Railway Conference*, 1817–1827.

Kim, J. D. (2018). *Application of human error causal analysis in railway accident risk analysis* [Master's thesis, Seoul National University of Science and Technology].

Kim, N. H., Im, H. K., & Yum, B. S. (2024). Human-error accident analysis for railway workers: Focus on the facilities domain. *Journal of Construction Health, 6*(2), 17–30.

Norman, D. A. (2013). *The design of everyday things* (Rev. & expanded ed.). Basic Books.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, 13*(3), 257–266. https://doi.org/10.1109/TSMC.1983.6313160

Reason, J. (1990). *Human error.* Cambridge University Press.

RSSB. (n.d.). Non-Technical Skills (NTS) resources for rail roles. *Rail Safety and Standards Board.* Retrieved September 24, 2025, from https://www.rssb.co.uk/knowledge-hub/insights-and-reports/non-technical-skills-nts-resources-for-rail-roles

Shappell, S. A., & Wiegmann, D. A. (2000). *The Human Factors Analysis and Classification System (HFACS)* (DOT/FAA/AM-00/7). FAA Civil Aeromedical Institute. https://www.faa.gov/data_research/research/med_humanfacs/oamtechreports/2000s/media/0107.pdf

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159–177. https://doi.org/10.1080/14639220210123806

Yum, B. S., Kim, T. Y., Choi, S. H., & Gal, W. M. (2024). A study on the cause analysis of human error accidents by railway job. *JWMAP, 7*(1), 27–33.

Kim, J. R., Yoon, S. Y., Yoo, S. W., Lee, S. J., Kim, W. Y., Seo, G. H., & Kim, Y. S. (2008). A cognitive–psychological approach to building a safety-management system to prevent construction worker errors (SMaSHE). *Proceedings of the Ergonomics Society of Korea Conference*, 2–7.