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Comparative case study of EAST, HTA, OESD and Sherpa methods in maintenance activities on high voltage electrical power networks.

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Maintenance activities on high voltage electrical power networks, particularly those conducted on energized systems above 13.8 kV, are among the most complex and safety-critical tasks in the energy sector. Such operations require not only technical expertise but also robust analytical methods capable of identifying human, organizational, and systemic factors that contribute to risk.

This study contributes by proposing an integrated human factors framework tailored to live-line maintenance, combining task, error, temporal, and systemic analyses. Trought a comparative case analysis of four recognized human factors and task analysis methodologies: Event Analysis of Systemic Teamwork (EAST), Hierarchical Task Analysis (HTA), Operator Event Sequence Diagram (OESD), and Systematic Human Error Reduction and Prediction Approach (SHERPA).

Through the application of these methods to simulated scenarios of live-line maintenance, the research examines their effectiveness in mapping task dependencies, predicting potential errors, and identifying systemic vulnerabilities. The results highlight that while HTA provides clarity in task decomposition, SHERPA adds predictive insight into error likelihood and mitigation strategies.

EAST contributes a systemic perspective by modeling communication, resource allocation, and interdependencies across teams, whereas OESD offers design-oriented guidance to reduce error susceptibility in procedures and tools. The comparative findings emphasize that no single method is sufficient in isolation; rather, an integrated approach enhances both process safety and worker safety.

The study employed simulated operational scenarios designed to replicate critical phases of professional maintenance operations in populated areas, including normal flight conditions, degraded system states, and emergency recovery situations, with the aim of observing adaptive strategies and decision-making under realistic constraints.

Keywords: Human Factors and Ergonomics, Risk Analysis, Working Safely with electricity.

1. Introduction

Maintenance activities on high voltage electrical power networks, especially those performed on energized systems exceeding 13.8 kV, represent the pinnacle of complexity and criticality within the energy sector.

This study delves into the critical requirements for safety management in such high-risk contexts by presenting a comparative analysis of four prominent human factors and task analysis methodologies: Event Analysis of Systemic Teamwork (EAST), Hierarchical Task Analysis (HTA), Operator Event Sequence Diagram (OESD), and Systematic Human Error Reduction and Prediction Approach (SHERPA).

Through the rigorous application of these methods to simulated live-line maintenance scenarios, our research systematically examines their individual and collective effectiveness.

Our findings reveal that each methodology offers distinct, yet complementary, insights. While HTA provides a clear, foundational understanding through detailed task decomposition, SHERPA extends this by offering predictive insights into error likelihood and guiding the development of targeted mitigation strategies.

Furthermore, OESD offers invaluable design-oriented guidance, focusing on reducing error susceptibility in existing procedures, tools, and system interfaces.

This research therefore contributes significantly to advancing contemporary safety management practices in critical infrastructure sectors, reinforcing the indispensable role of comprehensive human factors frameworks for effective risk reduction.

1.1. *Risk scenario in activities with live lines.*

"Work on live lines" includes interventions performed on energized installations to maintain power supply continuity and system reliability. In Brazil, this topic is anchored, at a minimum, in NR-10 (safety in electrical installations and services) and, when there is exposure to unevenness, in NR-35 (working at height). NR-10 requires risk management, qualifications, and written procedures in all phases (generation, transmission, distribution, and consumption), while NR-35 requires risk analysis, work permits, and protective measures before beginning work at height.

The primary hazards are electric shock (direct/indirect contact, touch and step potential differences, induction) and arc flash (thermal energy and pressure wave). Shock control requires configuration planning, equipotential bonding, effective grounding paths, and adherence to minimum approach distances (MAD).

MADs must be calculated considering voltage class, transient overvoltages, and working conditions, maintaining a creepage distance in air or through an insulating tool. IEC 61472 (and its part 2 for 1–72.5 kV) describes methods for determining the electrical component of MAD and serves as a reference for designing safe AC approximations.

Effective mitigation requires: defining the appropriate work method for the case (distance/insulated contact/same potential), calculating and adhering to MADs; standardized tooling maintained under testing/cleaning; properly specified arc flash PPE/EPCs; and a management system that ensures qualification, standardized communication, dynamic risk analysis, and active supervision.

1.2. *Time available for activities involving live line work*

In maintenance and operation activities involving energized installations (live lines), safety depends not only on technical standards and PPE: it is intrinsically dependent on teamwork—number, roles, skills, coordination, and communication.

Team size and composition are a result of operational and human factors:

(1) Work method (hot-stick/remote; gloves and insulating coverings; equal potential) — each method imposes different task, observation, and support arrangements (IEEE Std 516).

(2) Voltage, topology, and accessibility — higher voltage, close parallel circuits, intersections, and access via basket/tower increase the need for dedicated observation and coordination.

(3) Environmental conditions — wind, light rain, and surface pollution compress operational margins and may require additional functions for scene control.

(4) Operations Center Interface — tasks that depend on maneuvers, blockages, and releases increase the communication burden and the need for a dedicated person responsible for operational communication.

(5) Residual risk and contingencies — when the severity of a plausible failure is high (shock/arc/fall), it is prudent to expand the team to ensure immediate assistance, scene management, and cognitive redundancy.

Translating the above determinants into objective management criteria:

• Scenario complexity: the greater the interaction with the system (adjacent lines, intersections, concurrent maneuvers), the larger the minimum team required to maintain dedicated observation and communication.
• Operational margins: if the MADs are compressed by the environment/geometry, add an observer and equipotential bonding support.
• Potential severity: arc/shock risk with serious consequences → requires immediate rescue presence (capable of operating the basket, lowering the victim, and initiating care).
• Communication burden: if there is a sequence of maneuvers with the operations center, decouple communication from the operator.
• Shifts and fatigue: tasks with extended hours/shift changes require additional time for briefings and cognitive redundancy (Åkerstedt & Wright, 2009; Caldwell, 2012).

On live lines, undersized teams tend to accumulate incompatible roles, increasing the likelihood of human error precisely where fault tolerance is low.

1.2.1. ***What is and what is the role of a Power Distribution Operation Center.***

The Distribution Operations Center (COD/COS/COI) is the 24/7 room that monitors and controls the medium-voltage electrical system (typically 13.8 kV, 15 kV, and 34.5 kV) through SCADA/ADMS and integrations with OMS (outage), GIS, and teleprotection.

It coordinates maneuvers, isolates faults, restores loads, releases work areas, and maintains communication with field teams and the sales/service center.

When equipment is remotely controlled, the COD sends commands to open/close, enable/block functions, and adjust parameters. Where there is no remote control (fuses, manual switches, others), the maneuver is performed locally by field personnel, but under the coordination of the COD.

Everything follows standardized three-part maneuvering and communication procedures (order, repetition, and confirmation).

To release work, the COD coordinates reconnection blocking, signaling/tagout, and de-energization assurance (when applicable), issuing releases/authorizations in accordance with NR-10 and internal procedures.

Typically, it opens and closes circuit breakers, reclosers, motorized switches, capacitor banks, regulators/OLTC, in addition to blocking recloses and adjusting taps—all to maintain safety, isolate faults, and restore power with the lowest possible risk.

2. Problem

Working on energized high-voltage lines, such as 13.8 kV lines, represents one of the most critical and high-risk activities in the electricity sector.

This practice, called live-line maintenance, is adopted when it is not possible to disconnect the grid, requiring direct intervention on energized circuits.

The interruption of these activities can compromise vital services to the population and generate large-scale losses, both economic and social.

Another aggravating factor is the complexity of coordination between teams. During maintenance procedures, there is constant interaction between the operations center, field teams, and technical supervisors, requiring precise synchronization in maneuvers and authorizations.

Any communication breakdown can result in improper energization or premature release of the line. Therefore, workplace safety depends both on technology and protective equipment (such as insulating rods, arc-resistant clothing, dielectric blankets, and controlled approach zones) and on an organizational culture of safety and operational reliability.

Finally, although energized maintenance is a well-established and, in many cases, indispensable practice, it must be technically justified and formally authorized by responsible engineers.

The use of this methodology must be accompanied by a detailed risk analysis (APR), meticulous planning of the stages, verification of electrical insulation and grounding, and constant monitoring of the surrounding weather and safety conditions.

3. Data Collection

This study is based on observations by live-line maintenance teams in the field; drones are not used for live-line maintenance.

Data were collected through direct observation of 20 professional during field maintenance work. Each participant was observed across approximately nine simulation runs, resulting in a total of about 180 observation instances.

Observations focused on task execution, decision-making strategies, adaptations to system variability, and responses to unexpected or degraded operational conditions.

3.1 Research design

This study adopted an exploratory qualitative case study design focused on the application and comparison of Human Factors methods in live-line maintenance activities performed on energized electrical distribution networks above 13.8 kV.

The research followed a sociotechnical systems perspective, considering that operational safety emerges from the interaction between workers, technologies, procedures, organizational constraints, and environmental conditions.

The study was structured as a comparative methodological analysis, aiming to evaluate how HTA, SHERPA, OESD, and EAST complement each other in identifying operational risks, coordination demands, communication vulnerabilities, and human error potential.

A multiple-method analytical strategy was adopted to strengthen empirical consistency and improve triangulation between task analysis, communication flows, cognitive demands, and systemic interactions.

3.2 Participants and operational context

The empirical investigation involved field monitoring of professional live-line maintenance teams operating in medium-voltage electrical distribution systems.

The observed teams were composed of:

- live-line electricians;
- field supervisors/team leaders;
- safety observers;
- and distribution operation center operators.

The activities analyzed included:

- installation and removal of insulating protections;
- conductor interventions,
- communication procedures with the operation center;
- switching coordination;
- and verification/confirmation activities during energized interventions.

Data collection considered operational variability, including:

- environmental conditions;
- communication load;
- simultaneous coordination tasks;
- and unexpected operational disturbances.

The operational scenarios analyzed were selected because they represent high-risk and high-reliability activities with elevated cognitive and coordination demands.

3.3 Data Collection Procedures

Data collection was conducted using methodological triangulation, combining:

- direct field observations;
- semi-structured interviews;
- document analysis;
- and operational procedure reviews.

Field observations were carried out during live-line maintenance activities on energized electrical networks. The observations focused on:

- task execution sequences;
- communication exchanges;
- coordination dynamics;
- adaptive behaviors;
- workload management;
- and operational deviations.

Semi-structured interviews were conducted with workers and supervisors using predefined guiding questions related to:

- operational safety;
- communication practices;
- resource availability;
- prior risk analysis;
- emergency response;
- and organizational support.

Operational documents analyzed included:

- work permits;
- task procedures;
- risk analysis forms;
- communication protocols;

- and safety requirements derived from NR-10 and internal utility procedures.

Field notes were systematically registered immediately after observations to preserve contextual accuracy and reduce retrospective interpretation bias.

3.4 Data Analysis and Comparative Application of Human Factors Methods

The analysis process followed a sequential and integrated methodological framework. Initially, Hierarchical Task Analysis (HTA) was applied to decompose live-line maintenance activities into goals, sub-goals, operations, and execution plans. This decomposition established the operational structure necessary for subsequent analyses.

Based on the HTA outputs, the SHERPA method was then applied to identify potential human errors associated with each task step. Error modes, consequences, recovery opportunities, and mitigation barriers were systematically classified.

Subsequently, the Operator Event Sequence Diagram (OESD) was developed to represent temporal interactions among operators, systems, equipment, and operational decisions. The OESD enabled visualization of synchronization demands, communication dependencies, and temporal coordination requirements during critical maintenance phases.

Finally, EAST (Event Analysis of Systemic Teamwork) was applied to model:

- task networks;
- communication networks;
- and information exchange networks.

The EAST analysis supported identification of:

- central communication nodes;
- systemic vulnerabilities;
- coordination bottlenecks;
- single points of failure;
- and resilience-supporting redundancies.

The comparative analysis between methods considered the following analytical dimensions:

- task decomposition capability;
- identification of human error mechanisms;
- representation of temporal coordination;
- visualization of communication dependencies;
- support for systemic interpretation;
- and applicability to critical electrical maintenance environments.

The integration of the four methods enabled a broader understanding of both work-as-imagined and work-as-done, strengthening the empirical basis for identifying operational risks and organizational vulnerabilities.

4. Cognitive ergonomics and human factors analysis

4.1. *HTA*

Hierarchical Task Analysis (HTA) serves as the foundation of all safety analysis, decomposing the main objective into a hierarchy of subtasks and operations. This activity "map" allows visualization of the logical sequence, dependencies, and complexity of each step of the process, from initial planning to final documentation.

The minimum number of professionals required for safe execution of 13.8 kV live-line maintenance is four, although this number may vary depending on task complexity:

2 Electricians: perform the direct field operations, working from the bucket truck and manipulating energized components.

1 Team Leader: coordinates the on-site operations, ensures communication with the Control Center, and supervises safety procedures

1 Control Center Operator: coordinates remotely, monitors the system (SCADA), and issues operational authorizations and confirmations.

This team configuration ensures redundancy in communication and safety verification, reducing the likelihood of individual failures and strengthening overall operational resilience.

The HTA provides a hierarchical structure of human actions, identifying dependencies and the logical sequence of work. However, while HTA describes what must be done and in what order, it does not define how human errors can occur at each step or how they can be mitigated.

4.2. *SHERPA*

The SHERPA method is widely used in human factors engineering to identify, classify, and mitigate potential human errors during the execution of critical tasks such as live-line electrical maintenance or line maintenance process, detailed in the context of the activity and in expert interviews (PARNELL, 2013).

While the HTA establishes what must be done and in what sequence, the SHERPA focuses on how and why an error might occur, and what barriers can prevent or correct it. The table below describes how to identify the errors.

The SHERPA analysis shows that the most probable errors during live-line maintenance are related to communication failures and attention lapses, especially in intermediate steps such as measurement, confirmation, and inspection.

It also highlights that the Team Leader and Control Center Operator play a key role in preventing errors, acting as verification nodes within the operational chain. These findings form the basis for constructing the Operator Event Sequence Diagram (OESD), which visualizes the temporal flow of events, interactions, and feedback between human and system elements.

4.3. *OESD*

The OESD is a behavioral analysis tool that illustrates the temporal sequence of events and interactions among operators, systems, and the environment in complex operations.

While HTA explains what must be done, and SHERPA identifies how errors may occur, the OESD represents who does what, when, and with whom (PARNELL, 2013).

This method provides a dynamic understanding of the live-line maintenance process, emphasizing key moments of decision-making, coordination, and communication that underpin safety and performance.

The OESD provides a temporal and relational perspective of live-line maintenance, showing how human and technological interactions unfold over time.

The analysis of the OESD demonstrates that the maintenance process in a 13.8 kV energized electrical network constitutes a highly complex sociotechnical system, characterized by multiple human–technological interactions, elevated cognitive workload, and a strong dependence on communication among agents.

Therefore, improvements should prioritize operator-facing controls: unambiguous readback protocols, dedicated communicator/spotter roles to offload cognitive demand, mechanical locking features for blankets, torque-feedback tools, and hold-points formally embedded in the sequence.

Although, the EAST model can then map the broader sociotechnical network, ensuring that organizational conditions consistently support operators at the sharp end, where safety is ultimately made.

4.4. *EAST*

EAST (Event Analysis of Systemic Teamwork) is a human factors method for modeling and evaluating complex sociotechnical systems—that is, teamwork mediated by technology, procedures, and communications.

It integrates and represents three main work networks: the task network (who does what, in what sequence/parallelism), the social network (who communicates/coordinates with whom), and the information/knowledge network (what data, alarms, orders, documents, and signals support decisions).

In practice, EAST builds "networks of networks" of real work and allows the application of simple metrics (e.g., centrality, density, critical paths) to locate bottlenecks, fragile dependencies, and single points of failure.

EAST provides an explicit framework for recognizing and strengthening these interdependencies before execution:

Communication and coordination: The social network highlights overload on a single link (e.g., an executor overlapping communication with the operations center and security surveillance) and supports the decision to separate critical roles (execute ≠ observe ≠ command).

Safe sequence and parallelism: The task network helps verify logical orders (block reclosing → test for absence of voltage → install temporary grounding, etc.), reduce rework, and insert waiting/timeout points in degraded conditions.

Information dependencies: The information network makes visible the sources that support decisions (SCADA/ADMS, maneuver orders, diagrams, weather) and where ambiguity/delay can lead to erroneous maneuvers; the use of "broken links" allows testing resilience in the event of a channel failure.

4.5. *Application of the EAST Method*

The 13.8 kV grid is a fundamental part of electricity distribution in urban and rural areas.

Live line maintenance is necessary to ensure continuity of supply without disconnecting consumers, but it involves extremely high electrical, mechanical, and human risks.

Live line maintenance on 13.8 kV networks is a complex process that requires discipline, specialized training, and the use of appropriate technological resources, as all activities occur with the network energized and, therefore, under high-risk conditions.

Once in the field, the first step is to organize the work area, isolating the space, marking the surrounding area, and ensuring that pedestrians or vehicles do not interfere with the operation.

The team then prepares the network by installing insulating blankets and barriers on the conductors near the intervention point, checking the voltage with appropriate measuring equipment, and confirming each step with the operations center.

For an in-depth analysis of data preparation and collection, and complete information collection, field monitoring was carried out on teams tasked with performing maintenance on energized lines.

4.5.1. *Interview questions*

(i) Interviewer: How is the activity performed?
(ii) Interviewer: What is the safest way to perform it?
(iii) Interviewer: What resources are available to perform the task?
(iv) Interviewer: What safeguards are in place to prevent fatalities during maintenance work?
(v) Interviewer: How is the prior risk analysis performed?
(vi) Interviewer: How is communication with the operations center maintained?
(vii) Interviewer: What minimum team is required to perform the task?
(viii) Interviewer: In the event of a technical failure, human error, or management failure, what should be done?
(ix) Interviewer: What technical preparation is required to form the team?
(x) Interviewer: What training and education is required for the person in charge/leader of the task?

Each question—such as "What is the safest way to perform the activity?", "What resources are available to complete the task?", or "How is prior risk analysis performed?"is no longer just an isolated query and becomes part of a system of relationships, in which the answers reinforce and feed other connections.

This approach helps identify information gaps, strengthen points of convergence, and, above all, clearly visualize how different dimensions of safety, communication, and technical preparedness interconnect in the daily operations.

At the same time, the network of propositions built from these questions becomes a practical tool for risk management and decision-making.

It allows for mapping scenarios of technical failures, human errors, or management failures, connecting them directly to the necessary safeguards and required team qualifications.

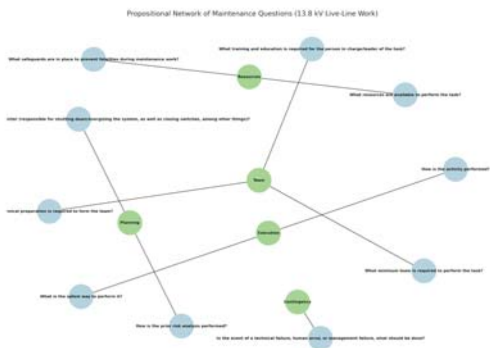

Fig. 1: proposition network based on the questions proposed to the teams of workers.

Connection between tasks and PPE/CPE: each activity is linked to the essential resource.
Example: “Replace live-line connector” requires a hot stick + insulating blankets + radio for continuous communication.

EAST highlights situations where resources are scarce, unavailable, or inappropriately shared, increasing the risk of improvisation.

4.5.2. *Systemic Interpretation*

Analyzing the three networks makes it possible to identify:

Critical nodes: tasks or people concentrating excessive responsibility (e.g., control center operator).

Cascade failure risks: if one communication fails, multiple subsequent tasks are compromised.

Desirable redundancies: secondary radio channels, double-checking insulation.

Cultural fragilities: pressure for rapid service restoration may lead to shortcuts and "normalization of deviance."

4.5.3. *Benefits of EAST in the Power Sector*

Prevention of fatal accidents: identifies not only human errors but also the systemic conditions that make mistakes more likely.

Training improvement: simulations can be adapted to strengthen weak nodes in the task/communication networks.

Critical risk management (live-line work): guides improvements in protocols, resource redundancy, and communication clarity with the control center.

Integration with Brazilian regulations: NR-10 (Electrical Installations Safety) and NR-35 (Work at Heights) can be operationalized with EAST insights, strengthening system resilience.

4.6. *Communications Usage Diagram (CUD)*

The diagram below visually represents the critical communication links. Bold, solid lines represent high-frequency, critical communication and coordination (step confirmation, constant status updates).

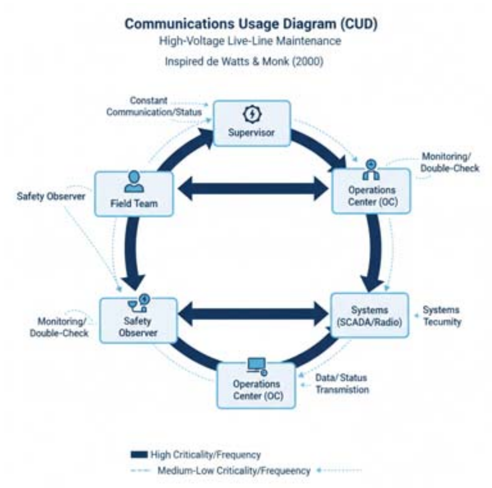

Fig. 2: CUD for high voltage live line maintenance.

4.7. *Coordination Demand Analysis (CDA) for High-Voltage Live-Line Maintenance*

This analysis identifies and details the critical coordination demands between the key actors involved in high-voltage live-line maintenance, drawing from the EAST propositions and the Communications Usage Diagram.

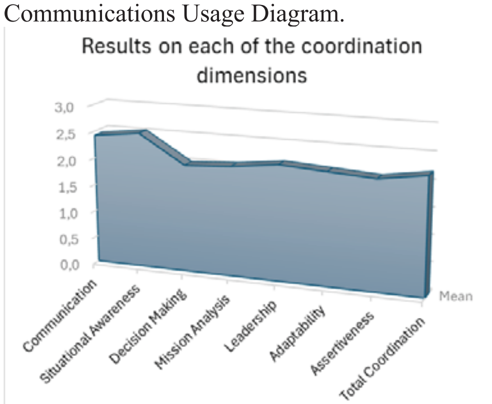

Fig. 3: profile of results on each of the coordination dimensions from CDA.

The CDA analysis applied to maintenance activities on high voltage electrical power networks highlights the significant coordination demands required to ensure safety and reliability.

Situational awareness stands out as a critical factor, as operators must constantly maintain and share a precise understanding of the network's state and the team's actions, particularly during live-line operations where even a brief lapse can have severe consequences.

Communication is also demanding: at every stage, from confirming isolations to coordinating live-line work, clear exchanges are essential, since any breakdown can immediately create hazardous conditions.

Decision-making also proved central, with phases such as resource validation or the choice of intervention methods requiring collective judgment.

This illustrates that safety depends not only on procedures but also on the team's ability to evaluate and decide together. Similarly, mission analysis at the start of the task is decisive, as incomplete understanding of objectives or risks can undermine the entire operation.

Leadership and assertiveness play complementary roles: the former ensures supervision and alignment, while the latter empowers workers to voice concerns that may prevent errors. Finally, adaptability is critical in responding to unexpected events, especially during testing or technical issues.

5. Discussion

The findings demonstrate that live-line maintenance on energized 13.8 kV electrical networks involves significant coordination, communication, and cognitive demands, particularly during task synchronization with the operations center and execution of safety-critical procedures.

The comparative application of HTA, SHERPA, OESD, and EAST showed that each method contributes differently to the understanding of operational risk. HTA supported the decomposition of maintenance activities into sequential and interdependent tasks, clarifying operational structure and identifying critical execution phases. SHERPA complemented this analysis by identifying probable error modes associated with communication failures, confirmation lapses, and inspection activities.

OESD expanded the analysis by representing temporal interactions between operators, supervisors, and control center personnel, highlighting how communication timing and synchronization influence operational safety. EAST provided a broader systemic perspective by mapping communication dependencies, coordination bottlenecks, and information flows across the sociotechnical system.

The combined use of these methods revealed that communication reliability and role coordination are central factors for maintaining operational safety during live-line interventions. The results also indicate that overloaded communication channels, role accumulation, and insufficient redundancy may increase operational vulnerability during critical maintenance phases.

Rather than replacing procedural compliance, the integrated Human Factors approach strengthened the understanding of how procedures, communication structures, and coordination mechanisms interact under real operational conditions. This reinforces the relevance of combining task-oriented and system-oriented methods when analyzing high-risk electrical maintenance activities.

6. Conclusion

This study analyzed the application of HTA, SHERPA, OESD, and EAST in live-line maintenance activities performed on energized electrical distribution networks above 13.8 kV.

The results demonstrated that the methods provide complementary perspectives for understanding operational safety. HTA contributed to task decomposition and identification of critical operational stages, while SHERPA supported the identification of potential human errors and associated preventive barriers. OESD highlighted temporal coordination and communication dependencies, whereas EAST enabled visualization of broader sociotechnical interactions, including information flows and organizational vulnerabilities.

The integrated application of these methods allowed a more comprehensive understanding of how communication, coordination, supervision, and operational decision-making influence safety performance during energized maintenance activities. The findings also reinforce the importance of communication redundancy, role clarity, and coordination support in reducing operational vulnerability in high-risk electrical work.

From a practical perspective, the study contributes to improving risk analysis, operational planning, and safety management practices in live-line maintenance environments, supporting both worker protection and operational reliability.

This study has limitations related to the exploratory qualitative design, the number of observed teams, and the use of field observations restricted to specific operational contexts. Future studies may incorporate quantitative performance indicators, physiological measures, and broader operational samples to expand analytical validation.

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