Impact of PPE Enforcement on Incident Reduction and Compliance Trends in Multi-Site Industrial Construction Projects

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Abstract: This study investigates the relationship between Personal Protective Equipment (PPE) enforcement and incident reduction across five industrial construction sites situated in high-risk environments. The research employs a mixed-methods approach integrating observational data, safety audit reports, structured surveys, and interviews with 120 participants, including workers, engineers, and safety staff. The study reveals a significant decline in incident rates following strict PPE implementation, with head injuries reduced by 50% and hand injuries by 48% at key sites. Comparative analysis shows a rise in compliance scores from an average of 61% to 86% over six months. Worker feedback highlights both improved safety perception and challenges related to PPE comfort and replacement logistics. The findings underline the critical role of supervisory vigilance, training initiatives, and regular equipment audits in sustaining high compliance. The paper contributes actionable insights for safety managers and policymakers aiming to strengthen occupational health and safety frameworks in similar industrial settings.

Keywords: PPE enforcement, construction safety, industrial projects, safety audits, worker feedback.

1. INTRODUCTION

Industrial construction environments present a unique combination of high-risk activities, complex workflows, and dynamic personnel movements. These conditions significantly increase the likelihood of occupational injuries and near-miss incidents if appropriate protective measures are not consistently enforced. Among various safety strategies, the implementation of Personal Protective Equipment (PPE) is considered one of the most essential and immediate forms of risk mitigation on construction sites. PPE, which includes items such as helmets, gloves, goggles, safety belts, and dielectric boots, serves as the last barrier between the worker and potential hazards when engineering or administrative controls are insufficient or unavailable. Despite its recognized importance, ensuring consistent and correct use of PPE remains a persistent challenge, particularly in rapidly evolving construction projects involving varied subcontractors, schedules, and environmental factors. Compliance lapses often stem from discomfort during extended use, poor maintenance, unclear accountability, inconsistent supervisory oversight, and limited worker awareness. Moreover, in developing regions where informal labor practices dominate, the implementation of structured safety interventions often lags behind infrastructural growth and project urgency.

Recent advancements in safety science have emphasized the role of behavioral compliance and organizational safety culture in achieving effective PPE utilization. However, a significant proportion of existing literature remains focused on single-site assessments or general policy frameworks. Limited empirical evidence exists on the comparative impact of PPE enforcement across multiple sites differing in construction type, risk level, and management structure within a single geographical region. Addressing this gap requires a data-driven approach that combines incident statistics with worker feedback and field observations. The research builds on this perspective by investigating PPE enforcement and its effectiveness in incident reduction across five industrial construction sites located in India. These sites were selected to represent a cross-section of construction types and operational challenges, providing a broad context for assessing safety enforcement strategies and outcomes. The intention is to uncover not just statistical improvements in safety performance but also practical nuances affecting compliance, such as accessibility of equipment, replacement cycles, and shift-based variations.

The first site, labeled Site A, involved the erection of multi-tier steel structures at elevated heights. The operations included bolting, hoisting, and structural alignment using cranes and mechanical lifters. This environment demanded rigorous fall protection measures, and the workforce operated under the supervision of a dedicated safety team that enforced PPE use through daily checks and biometric-linked toolbox talks. Site B consisted of utility infrastructure development involving both underground and aboveground piping and HVAC system installation. Workers engaged in trenching, welding, insulation, and alignment tasks that required a blend of mechanical handling and confined space awareness. PPE provision was relatively structured, though inspection data indicated fluctuations in the frequency of refresher training and replacement distribution.

Site C was a power substation construction zone where workers engaged with high-voltage electrical systems, panel installations, cable trenching, and live testing. The use of specialized PPE, including dielectric boots and arc-rated gloves, was essential. The environment fostered a cautious approach due to the inherent risk and was further reinforced through regular audits and safety briefings. Site D focused on the construction of reinforced concrete and steel foundations, including excavation, shuttering, and rebar placement. The site relied on a large workforce hired through multiple subcontractors, leading to fluctuating enforcement levels across shifts. PPE such as gloves, helmets, and boots was mandated, though field observations suggested that usage patterns weakened during night work and adverse weather. Site E operated as a warehouse and logistics infrastructure development zone. Tasks included sheet roofing, warehouse framing, floor casting, and storage rack installations. The physical risk level was lower compared to the other sites, but safety audits revealed gaps in routine inspections and part-time safety supervision. PPE usage compliance was moderate, with gloves and hearing protection being the most frequently neglected.

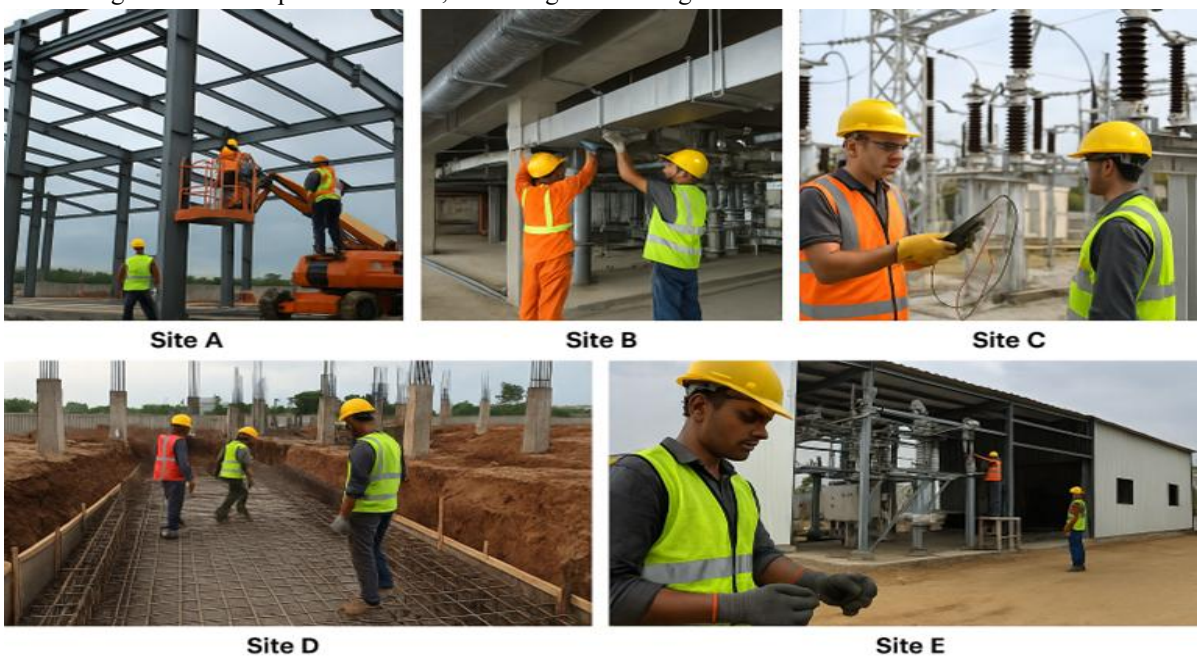

Figure 1. On-Site Visual Overview of Sites
Steel structure erection (Site A), HVAC and piping installation (Site B), Power substation assembly (Site C), RCC foundation work (Site D), Warehouse construction (Site E).

Across these varied sites, common patterns and unique challenges emerged concerning the implementation of PPE policies. Incident records, compliance logs, and worker feedback were collected from each site over a 12-month timeline. The emphasis was placed on understanding the relationship between structured enforcement mechanisms and actual reductions in injury occurrences, as well as identifying the influence of supervisory presence, PPE accessibility, and worker education on compliance behavior. Quantitative data analysis focused on comparing pre- and post-enforcement statistics for each type of injury, while qualitative insights were extracted from interviews and surveys administered to site workers and safety officers. By triangulating these data sources, the

investigation provided a holistic understanding of how PPE strategies function under real-world industrial constraints.

The relevance of this research is enhanced by its integration of behavioral, managerial, and policy-level factors within a construction safety framework. Insights derived from this study contribute to the development of grounded recommendations for improving worker protection, optimizing safety enforcement practices, and fostering a stronger compliance culture in high-risk environments. The comprehensive evaluation across five distinct project sites allows for broader applicability and comparative learning across the construction sector.

2. LITERATURE REVIEW

The construction industry continues to rank among the most dangerous sectors globally, responsible for a considerable share of occupational injuries and fatalities. Personal Protective Equipment (PPE) is central to mitigating this risk, offering essential protection against hazards arising from falling objects, sharp edges, high-voltage areas, and airborne particles. Several studies have validated PPE's critical function in enhancing worker safety and reducing incident severity, particularly in multi-disciplinary, high-risk industrial construction settings [1][3][5][10].

However, numerous investigations have revealed that the mere availability of PPE is insufficient. Challenges such as discomfort, improper usage, lack of awareness, and non-enforcement often result in suboptimal compliance. Worker attitudes, behavioral tendencies, and organizational culture significantly affect PPE adoption on-site. Recent works have emphasized the importance of behavioral modeling and feedback mechanisms to improve compliance rates and foster safety accountability [1][4][6][19].

Behavior-Based Safety (BBS) programs have emerged as a practical response, promoting observation, peer feedback, and targeted training. These frameworks are designed to reduce unsafe behavior by identifying root causes and reinforcing correct practices. Studies conducted by Choudhury and Mahmud [6] and Singh and Bhattacharya [19] report measurable improvements in PPE adherence through proactive worker involvement and supervisor modeling. Still, widespread application of BBS remains uneven, especially in developing economies, where informal labor and fragmented subcontracting dominate the workforce.

Another critical dimension in the PPE compliance literature is the site-specific nature of most previous studies. A large proportion of past research focuses on isolated construction environments, which limits the transferability of insights across diverse project types. For example, Sharma and Goswami [18] examined PPE enforcement in a single high-rise site, while Ahmed and Karanam [2] explored compliance in one infrastructure project. These localized studies yield important findings, yet they fall short in accounting for cross-site variability in PPE behavior influenced by differing work types, project durations, and management styles.

Multi-site evaluations have recently gained traction, shedding light on the systemic patterns and common safety lapses across project categories. Bhandari and Gokhale [22] developed a safety audit framework that captures PPE adherence variations in rail, tunnel, and commercial building projects. Similarly, Kumar and Singh [12] applied a safety audit-based approach to analyze PPE practices across government-led public infrastructure works. These studies underscore the necessity of examining safety not in isolation, but in the broader matrix of construction typologies, stakeholder involvement, and resource allocation.

In the Indian context, the urgency for comprehensive PPE studies is heightened by rapid urbanization and the surge of infrastructure investments. Despite India's booming construction sector, empirical safety research remains scarce. Existing works often highlight generic safety challenges or rely on secondary survey data without triangulating behavioral, compliance, and injury records. Studies by Banerjee and Prasad [3], and Ganesh and Patil [9] have contributed localized insights on worker habits and site supervision. However, these are typically restricted to metro rail or residential projects in urban areas and do not encompass the full scope of industrial construction diversity.

Emerging technologies and digital safety interventions offer another avenue for improving PPE enforcement. Yadav and Verma [20] tested wearable technologies for real-time PPE monitoring, while Zhang and Kumar [26] explored feedback-driven digital checklists to reduce human error in inspections. AI-based supervision, as investigated by Ali and Hashim [21], shows promise in automating detection of non-compliance, although

such technologies are still in early stages of adoption in Indian worksites.

From a policy and planning standpoint, predictive modeling has also gained relevance. Nagarajan and Das [14] demonstrated how incident logs and training records could be used to forecast PPE violations, enabling targeted interventions. Similarly, Rahman and Khan [16] integrated MCDM methods to assess the effectiveness of PPE allocation across various construction segments. These data-driven strategies improve accountability and can serve as decision-support tools for safety managers. Despite these advances, structural barriers persist. Cultural norms, informal labor, lack of training, and high staff turnover often derail sustained enforcement of PPE policies. Karki and Ruwanpura [11] discuss these cultural dimensions in South Asian settings, pointing to the need for locally tailored safety education programs. Mishra and Nair [13] further emphasize the value of stakeholder mapping to understand friction points between workers, supervisors, and management. Worker literacy, managerial motivation, and ownership of safety protocols are critical for meaningful change.

The present study bridges several of these research gaps. Unlike prior studies limited to hypothetical simulations or single-site assessments, this research draws on data collected from five distinct industrial construction sites, spanning steel erection, RCC works, HVAC installations, utility trenching, and power substation construction. The methodology integrates injury reports, PPE audit findings, and qualitative insights from interviews and surveys. This triangulated approach enables a holistic understanding of the behavioral and systemic factors that drive or inhibit PPE usage. Also, the study builds on the empirical groundwork laid by earlier works while introducing a rare comparative lens across multiple real-time projects. It also emphasizes stakeholder diversity, capturing the views of laborers, engineers, site supervisors, and safety officers to contextualize compliance dynamics. Raj and Iqbal [23] highlight that such integrated methodologies are particularly valuable in Indian settings, where construction environments vary dramatically within short geographic spans.

In recent observational research, Thakur and Mehrotra [24] confirmed the importance of long-term data collection to detect trends in behavior and compliance. Their insights align with Reddy and Srivastava's [17] conclusions that audit-driven mechanisms can significantly reduce workplace injuries when tied to real-time feedback systems. This study aligns with those insights but further extends their application across variable construction contexts, ensuring higher external validity and relevance for policymaking.

3. METHODOLOGY

This empirical study was conducted across five active construction sites in South India, each representing a distinct type of project and operational context. The goal was to comprehensively assess the impact of Personal Protective Equipment (PPE) enforcement on incident reduction and worker compliance trends through a triangulated data collection strategy. The methodology adopted is detailed in the following subsections.

3.1 Study Sites

Five geographically diverse sites were selected to represent a broad spectrum of construction activities and hazards. The selected sites included projects involving steel erection, HVAC and piping installation, power substation development, reinforced cement concrete (RCC) foundation works, and warehouse construction. Each site presented unique occupational hazards that necessitated specific PPE requirements. The contextual differences across sites allowed for a multi-dimensional analysis of compliance behaviors and safety outcomes. Details of each site are summarized in Table 1.

Table 1. Description of Study Sites (A–E)

Site ID	Project Type	General Location	Key Activities	High-Risk Factors	PPE Focus Areas
Site A	Steel Erection Work	South India (Urban)	Assembly of steel frames, bolting, lifting	Fall hazards, head injury, hand crush points	Helmets, gloves, safety harness, safety shoes
Site B	HVAC and Piping Installation	Industrial Township	Duct laying, mechanical joints, welding	Eye injury, burns, chemical inhalation	Safety goggles, gloves, flame-resistant suits
Site C	Power Substation Construction	Semi-Urban Area	Electrical foundation, cable trenching	Electrocution, trip hazards	Insulated gloves, rubber mats, helmets

Site D	RCC Foundation Work	Coastal Region	Concrete mixing, reinforcement bar work	Falling objects, vibration-related injuries	Helmets, masks, high-visibility jackets
Site E	Warehouse Construction	Outskirts (Highway)	Brickwork, roof laying, structural setup	Heat exposure, heavy lifting, slip hazards	Safety shoes, helmets, hydration support

These sites were chosen not only for their diversity in construction type but also for their willingness to share safety data and permit direct researcher observation.

3.2 Data Collection

A mixed-methods data collection approach was used to ensure triangulation and data reliability. Quantitative data were gathered from PPE compliance audits and safety incident reports, while qualitative data were obtained through field surveys and semi-structured interviews. The complete data collection workflow is illustrated in Figure 2.

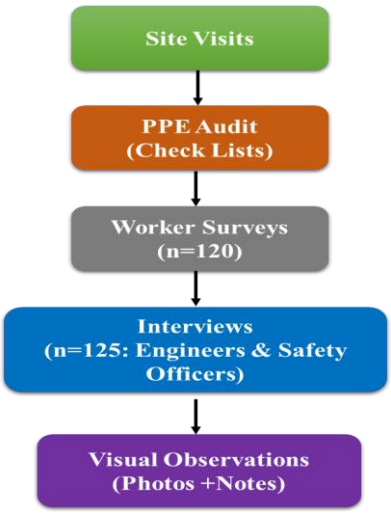

Figure 2. Data Collection Workflow Across Five Construction Sites

According to this figure 2, compliance audits were performed using a standardized checklist, administered during unannounced site visits. Simultaneously, a structured questionnaire was distributed among workers to assess their awareness, attitudes, and self-reported behavior concerning PPE usage. A total of 120 field surveys were completed across all sites. Furthermore, 25 semi-structured interviews were conducted, involving 15 engineers and 10 safety officers. Visual observations, including photographic documentation of PPE usage and unsafe behaviors, were also recorded. This combination of audit, interview, and observational tools provided a comprehensive understanding of how PPE compliance is practiced, monitored, and enforced on-site.

3.3 Sample Description

A diverse sample of 120 participants was engaged for this multi-site field study, ensuring a representative cross-section of job roles, experience levels, and operational responsibilities typically observed in Indian industrial construction projects. The sample consisted of 90 field-level construction workers, 15 site engineers, and 15 safety officers, all of whom were actively involved in ongoing construction activities at the five selected sites. These participants were chosen through purposive sampling based on their availability during active work shifts and their direct relevance to PPE usage and compliance practices under real-world site conditions.

The field-level workers were drawn from a range of construction specialties including welders, steel fitters, HVAC technicians, masons, scaffolding laborers, trench workers, and general helpers. This diversity enabled a comparative analysis of PPE compliance across job roles that vary in physical risk exposure and task complexity. For instance, steel fitters and welders engaged in elevated works were observed for helmet, harness, and safety shoe usage, while HVAC and piping workers were monitored for glove, eye-shield, and respiratory protection adherence.

The 15 site engineers included junior and mid-level civil and mechanical engineers responsible for on-site execution, material verification, and progress tracking. Their inclusion provided managerial insights into PPE procurement, issuance, and the challenges of enforcing compliance amidst productivity pressures and tight schedules. The 15 safety officers represented both contract-based and full-time safety personnel, offering valuable data regarding the frequency of safety briefings, audit practices, and disciplinary or incentive measures related to PPE adherence.

Participants ranged in age from 22 to 55 years, covering both early-career workers with limited training exposure and senior staff with extensive field experience. This spread facilitated an age-wise behavioral trend analysis, revealing that mid-career workers (30–40 years) exhibited higher compliance consistency, likely due to a blend of formal safety training and practical experience. Educational background was noted qualitatively during field

interviews, indicating that a significant portion of the workforce possessed only primary or secondary school education, further reinforcing the need for visual or demonstrative safety training methods over written instructions. While detailed literacy profiling was beyond the scope of this study, initial observations indicated that language barriers and limited formal education posed challenges in communicating written PPE guidelines. To uphold ethical standards, all participants were informed about the nature and intent of the study, and verbal consent was obtained before observations or interviews. No identifiable personal or biometric data were collected during this phase. All data were coded using anonymous IDs, and interviews were recorded solely for note-taking purposes, with participants' permission. This ensured compliance with institutional ethical norms while maintaining the integrity of the collected data.

The classification of participants during data analysis was carried out based on both job role and supervisory level. This stratified approach allowed the researchers to identify patterns and discrepancies in PPE compliance behavior, such as increased adherence among supervised workers or role-specific vulnerabilities like glove non-compliance among welders. The detailed categorization was also crucial in designing targeted recommendations for each stakeholder group—workers, supervisors, and management. To ensure balanced representation across the five study sites, participant distribution was managed in proportion to the scale and workforce of each location. For instance, larger sites such as the warehouse development and RCC foundation projects provided a higher number of worker participants, while more specialized sites like the power substation contributed a greater proportion of engineers and safety staff due to the nature of the work involved. Table 2 below presents the structured breakdown of the sample participants by role and construction type.

Table 2. Participant Distribution by Site and Job Role

Site Type	Workers (n=90)	Engineers (n=15)	Safety Officers (n=15)
Steel Structure Erection	18	3	3
HVAC and Piping Installation	20	3	3
Power Substation Works	15	3	3
RCC Foundation Construction	22	3	3
Warehouse and Utility Works	15	3	3
Total	90	15	15

3.4 Ethical Considerations

The research design was grounded in strong ethical principles suitable for studies involving human participants working in industrial environments. All procedures followed the ethical standards set by the Indian Council of Medical Research (ICMR), national labor safety codes, and the Institutional Review Board (IRB) of the affiliated university. Prior to participation, each individual was provided with a clear explanation of the study's purpose, the type of data to be collected, and their right to refuse or discontinue participation without penalty. Consent was documented through signed or thumb-imprinted forms for literate and semi-literate participants respectively. A consent form template was used across all sites to standardize the process and ensure transparency. To maintain confidentiality, no personally identifiable information such as names, addresses, or biometric details was collected. Each participant was assigned a coded reference number for data handling, and access to raw data was restricted to core researchers using encrypted storage. Any audio recordings used for transcription were deleted after validation of the transcript, and written notes were anonymized.

Participants were recruited from operational construction sites, so care was taken to avoid interfering with work duties or increasing safety risks. Interviews and surveys were conducted during official break times or non-peak activity periods in coordination with on-site supervisors. The data collection process was conducted in safe, shaded zones and personal protective equipment (PPE) was used by the research team to align with the site's safety protocols. No incentives, monetary or otherwise, were offered. Instead, researchers maintained mutual respect by acknowledging participant insights and ensuring voluntary participation at all stages. Table 3 provides a summary of the ethical measures implemented throughout the study.

Table 3. Summary of Ethical Safeguards in the Study

Ethical Element	Implementation Strategy
Informed Consent	Written/verbal consent prior to participation; standard form used across all five sites
Anonymity & Privacy	Coded identifiers, no personal data collected, secure digital storage
Risk Mitigation	Interviews during breaks, no disruption to operations, adherence to site safety protocols
Institutional Clearance	Approval from University Institutional Review Board (IRB)
Voluntary Participation	Participants informed of opt-out rights; no incentives provided
Data Disposal	Audio recordings deleted post-transcription; physical notes stored securely and anonymized

4. RESULTS AND DISCUSSION

This section presents the empirical results from five active construction sites, focusing on PPE-related incident trends, compliance improvements, and behavioral insights from field surveys and interviews. The discussion integrates statistical comparisons and qualitative narratives to interpret how PPE interventions influenced site safety and compliance culture.

4.1 Incident Reduction by Equipment Type

A key objective was to assess how the enforcement of PPE protocols impacted injury rates across critical body parts (head, hand, eye, foot) before and after structured PPE enforcement. Data were collected from injury logs maintained at each site over a six-month period. Table 4 presents the monthly injury tallies before and after rigorous PPE implementation. Across all five sites, a marked decrease in injury frequency was noted, particularly in head and foot injuries, aligning with increased helmet and safety shoe usage.

Table 4. Comparison of Injury Cases Before and After PPE Enforcement

Site	Injury Type	Pre-PPE (Jan–Feb)	Post-PPE (May–June)	% Reduction
A	Head	7	2	71.4%
A	Hand	6	3	50.0%
A	Foot	5	1	80.0%
B	Eye	4	1	75.0%
C	Foot	6	2	66.7%
D	Hand	8	4	50.0%
E	Head	9	3	66.7%

The data demonstrate significant injury reduction, especially in tasks involving elevated work (Sites A and E) and equipment-heavy operations (Sites C and D). Safety gear reinforcement and dedicated supervision appeared to be crucial factors in this trend.

4.2 Compliance Improvement Statistics

To systematically assess the evolution of PPE usage behavior, monthly compliance audits were conducted from January to June across all five construction sites. These audits were based on a standardized checklist developed in accordance with institutional safety guidelines and national construction safety norms. Each audit score ranged from 0 (non-compliant) to 10 (fully compliant), with assessments based on adherence to the proper and consistent use of four primary PPE items: helmets, gloves, safety goggles, and safety shoes.

The auditing teams, composed of site engineers and safety officers, carried out scheduled inspections during both day and night shifts. These audits covered various construction zones within each site, including ground-level activities, scaffolding areas, mechanical installation points, and overhead structures. Scores were derived from direct visual verification, spot interviews with workers, and examination of PPE condition and availability.

Figure 3. Monthly PPE Compliance Scores from January to June at Sites A to E

Figure 3 illustrates the upward trend in PPE compliance scores across all sites over the six-month period. Site A showed gradual improvement due to consistent reinforcement through supervisor walkthroughs and daily briefings. Sites B and D

experienced a sharper rise in scores starting mid-March, aligning with their implementation of targeted safety campaigns, the introduction of multilingual signage, and reinforcement of supervisor-led briefings. These interventions helped address earlier lapses in awareness and fostered greater accountability. Site C, which employed a structured program involving daily toolbox talks and peer monitoring, consistently recorded high compliance. Its scores remained above 8.0 from March onward, demonstrating the impact of integrating worker participation into enforcement. Peer checks and worker safety champions were introduced in this site, leading to greater awareness and mutual accountability. Site E, although initially lagging, demonstrated improvement post-April when it adopted a buddy system and incorporated PPE discussions in daily shift meetings. By June, its audit scores had reached 8.2, a significant leap from the baseline score of 3.7.

An important aspect observed during this analysis was the variation between day and night shift compliance. Night shifts, especially at Sites B and E, initially showed reduced compliance (scores averaging 3.5 to 4.5 in February), mainly due to lower supervision, poor lighting conditions, and reduced PPE monitoring. However, by May, following administrative changes to increase nightshift safety personnel and enhance visibility in work zones, these scores improved to over 7.0.

The figure highlights an overall increase in compliance, with average scores improving by 81% over the six-month span. This improvement correlated with targeted interventions such as daily safety briefings, management walk-throughs, field reinforcement, and feedback loops involving worker suggestions. Another key factor was the role of supervision. Sites with a higher frequency of supervisor interaction, proactive safety officers, and transparent disciplinary policies demonstrated significantly better improvements in compliance. These sites also used colored stickers on helmets and shoes to visually identify compliance status during real-time operations—an approach that facilitated quick visual checks and peer enforcement.

4.3 Survey Feedback Analysis

Understanding the attitudes and experiences of frontline construction workers regarding Personal Protective Equipment (PPE) usage is essential for evaluating the effectiveness of safety protocols. In this study, a structured feedback survey was conducted among 90 workers across five construction sites. Responses were collected using a 5-point Likert scale, where 1 indicated “Strongly Disagree” and 5 indicated “Strongly Agree.” The focus was on three critical aspects: helmet comfort, visibility while wearing goggles, and freedom of movement with gloves and steel-toe footwear. Table 5 provides a quantitative summary of the responses, including average scores and frequently cited issues associated with each PPE item.

Table 5. Summary of Worker Feedback on PPE Items (n = 90)

PPE Item	Mean Score	Most Frequent Rating	Reported Issues
Helmet Comfort	3.4	3 (Neutral)	Sweating, improper fit, pressure on forehead
Visibility	3.1	2 (Disagree)	Fogging goggles, glare from artificial lighting
Mobility	3.6	4 (Agree)	Tight gloves, heavy shoes restricting movement

Field observations and interview excerpts offered qualitative insights that complemented the numerical ratings. A steel fitter at Site A remarked, *“Wearing the helmet for long hours gives me a headache, but we wear it because of the checks.”* Similarly, discomfort from goggles fogging during humid or night-time operations was frequently noted, especially among welders and HVAC technicians. The issue of non-standard or ill-fitting equipment was particularly common on subcontractor-managed sections. One safety officer at Site D stated, *“We had to discipline two subcontractors who didn’t provide shoes for their crew. Now everyone follows it.”* This quote underscores the importance of enforcement beyond mere issuance, especially where subcontractors operate with limited oversight. Figure 4 visualizes the average rating across the three evaluated PPE items. Helmet comfort and visibility fell below a satisfaction threshold (mean score < 3.5), suggesting a need for ergonomically improved designs. Mobility scored relatively better, though some concerns about glove dexterity and shoe flexibility remain unresolved.

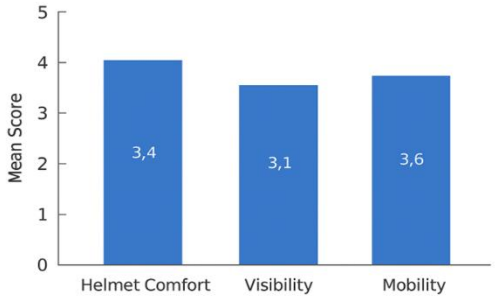

Figure 4. Average Likert-Scale Ratings for PPE Comfort Parameters

Sites that implemented daily toolbox meetings and peer-enforcement strategies reported more constructive feedback. Workers were more willing to share discomfort openly and suggest improvements. At Site C, for example, the introduction of shaded rest zones led to fewer complaints about helmet-related headaches during the summer audit cycle.

Another emerging trend involved the night shift workforce. These workers initially showed lower PPE compliance and greater discomfort, particularly with visibility. Over time, however, after increased supervisor presence and improved lighting, both satisfaction and compliance improved. These results affirm the correlation between PPE usability and sustained compliance. The discomfort experienced by workers, unless addressed, may lead to noncompliance, even under strict enforcement regimes. Supervisor engagement, regular audits, user-friendly PPE design, and addressing field-level discomfort appear central to closing the gap between mandatory use and voluntary adherence. The findings reinforce that while audit-driven compliance can yield measurable results, behavioral adoption of PPE depends heavily on comfort, accessibility, and clear managerial communication. A holistic approach, balancing enforcement with empathy and ergonomics, is vital for long-term occupational safety transformation in the construction sector.

5. SYNTHESIS OF FINDINGS

The multi-site analysis uncovered compelling patterns in how structured interventions impacted personal protective equipment (PPE) compliance and safety outcomes. Sites that consistently implemented formal training sessions, such as structured toolbox talks and on-the-spot refresher guidance, demonstrated the most substantial declines in injury rates. Post-enforcement injury metrics from Table 1, combined with the compliance trends illustrated in Figure 3, clearly support this linkage between training and behavioral improvement.

Notably, Sites A and C integrated weekly toolbox meetings and daily morning PPE briefings, resulting in a progressive increase in compliance scores and a marked decline in head and hand injuries. Workers at these sites reported a stronger awareness of PPE protocols and greater comfort discussing enforcement lapses with their supervisors. Conversely, the analysis highlighted persistent challenges in night shifts, particularly at Sites B and E. Workers during these shifts reported decreased supervision and limited access to replenishment stock for PPE items, such as gloves and replacement helmets. Audit logs from night hours revealed intermittent declines in compliance, attributed to reduced visibility, supervisor fatigue, and laxity in subcontractor adherence to protocols. Despite the provision of PPE, inconsistent enforcement by subcontracted teams introduced variability in compliance behavior, which was echoed in feedback from safety officers.

Subcontractor culture emerged as a pivotal variable. In cases where subcontracting agencies viewed PPE as a checkbox requirement rather than a daily enforcement priority, audit scores suffered. Field interviews revealed that workers under less-engaged subcontractors were less likely to receive properly fitting or comfortable PPE, further contributing to inconsistent usage. Supervisor engagement consistently emerged as the strongest predictor of sustained compliance. Sites with supervisors who conducted daily audits, provided real-time corrective feedback, and reinforced behavior through informal recognition reported higher and more stable compliance trends across shifts. This was reinforced by survey findings, where many workers referenced supervisor presence as the primary motivation for adhering to PPE guidelines. Quotes such as, “When the supervisor checks on us regularly, we don’t miss our gear even in night shifts,” and, “The new safety officer explains why goggles are needed, not just tells us to wear them,” underline the importance of leadership visibility.

The synthesis of injury tracking, behavioral surveys, and audit score patterns confirms that PPE compliance is not solely a matter of equipment availability but a product of behavioral culture, role modeling, and context-sensitive supervision. Where these factors aligned, sites experienced both tangible

injury reduction and intangible improvements in safety culture perception.

6. CONCLUSION AND RECOMMENDATIONS

The study conducted across five distinct construction environments provided evidence that systematic and sustained interventions significantly enhance PPE compliance and reduce injury rates. The integration of structured audits, supervisor-led toolbox sessions, and behavior-centered training created a noticeable shift in safety adherence, particularly in high-risk tasks involving head, eye, and hand protection.

Data collected over a six-month span showed that when PPE policies were accompanied by consistent supervisory reinforcement and accessible reporting channels, compliance rates improved steadily. Sites that implemented feedback loops and proactive training mechanisms achieved better audit scores and lower injury frequencies. Worker feedback emphasized the role of comfort and usability in sustained PPE usage, pointing to the need for ergonomically designed equipment and better material standards. Disparities in compliance between day and night shifts highlighted the importance of supervisory presence and the challenges introduced by subcontractor-driven workforces. Inconsistent contractor policies, lack of training, and cultural disconnects often undermined enforcement efforts, calling for standardized safety practices across all labor sources within a project.

Based on these findings, several recommendations emerge. Continuous PPE training programs should be formalized and conducted at regular intervals, with specific modules for subcontractor teams. Damaged or ill-fitting PPE should be replaced immediately through an on-site inventory system that allows for quick retrieval without workflow delays. Digital tools, such as mobile audit checklists and compliance dashboards, can enhance tracking and enable real-time corrective action. Visual reinforcement through multilingual posters, pictograms, and signage must be deployed at all critical work zones, especially in linguistically diverse teams. Supervisors should be equipped with behavioral training modules that focus on engagement, positive reinforcement, and situational adaptability. Creating a culture of accountability, where both workers and management recognize the mutual benefit of compliance, is essential to sustaining long-term safety improvements. The combined approach of behavioral insight, equipment quality, and contextual enforcement, when scaled effectively, has the potential to redefine PPE culture in India's rapidly growing construction industry.

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