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Impact of the occupational safety and health management system (OSHMS) on the reduction of occupational risks in high-risk construction activities

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Abstract

The construction industry is characterized by high exposure to occupational hazards due to the coexistence of critical tasks, changing operational conditions, and frequent deficiencies in preventive management, all of which increase the likelihood of accidents and operational losses. In this context, the present study aimed to evaluate the effect of implementing an Occupational Safety and Health Management System (OSHMS) on system compliance, occupational risk reduction, and economic implications in a highly complex hospital construction project executed in Casma, Peru. A quantitative, applied study with a pre-experimental before-and-after design was conducted in three phases: baseline diagnosis, OSHMS implementation under the Plan–Do–Check–Act (PDCA) cycle, and post-implementation evaluation. The baseline was established through document review, field observation, and application of a Hazard Identification, Risk Assessment, and Control (HIRAC) matrix, while the analysis included descriptive statistics, Pearson's chi-square test, and benefit–cost evaluation. The results showed that overall OSHMS compliance increased from 22.5% to 79.0%, with substantial improvements in procedures for critical tasks, incident investigation, training, and risk control. Likewise, high-risk conditions decreased from 41% to 0%, low-risk conditions increased from 16% to 61%, and minor accidents declined from four to one, with the cumulative frequency rate decreasing from 39.80 to 9.60. Pearson's chi-square test confirmed significant differences in the distribution of risk levels before and after the intervention (69.319, $p < 0.001$). In conclusion, OSHMS implementation substantially improved preventive performance, reduced the severity of occupational exposure, and proved to be economically favorable in a high-risk construction environment.

1. Introduction

The construction industry remains one of the economic sectors with the highest exposure to accidents and high-severity events due to the coexistence of critical tasks, changing workface conditions, and constant interaction among technical, organizational, and human factors. In this context, the literature has shown that safety in construction cannot be understood solely as the result of individual worker behavior, but rather as an emergent property of project management, operational planning, and the preventive maturity of the organization. In particular, Yoon et al. (2013) demonstrated that the implementation of occupational safety and health management systems can reduce occupational accident rates, while Arévalo Sarrate et al. (2024) confirmed that management systems in construction are associated with measurable improvements in preventive performance. Along the same line, Karanikas et al. (2022) argued that ISO 45001 should be understood from a systemic perspective, and Kajumulo et al. (2024) showed that safety in building projects depends more on interrelated organizational dynamics than on isolated controls.

Occupational risks in construction intensify when work at height, electrical activities, load handling, confined or restricted workspaces, and simultaneous tasks involving different trades converge. Recent studies have indicated that the main critical events in the sector continue to concentrate in falls, electrocutions, struck-by-object incidents, caught-in/between events, and overexertion, all of which have

a high potential to cause serious or fatal injuries. In this regard, Tripathi and Mittal (2025) reinforced the need to systematically prioritize hazards such as falls from height in risk assessment and ranking methodologies. Complementarily, Golabchi et al. (2024) emphasized that construction safety requires combining leading and lagging indicators to capture both potential exposure and actual performance, while Choudhry et al. (2023) highlighted the value of proactive approaches for measuring safety management in building projects.

In response to this scenario, Occupational Safety and Health Management Systems (OSHMS), together with OHSMS and ISO 45001 frameworks, have gained relevance as tools capable of formalizing responsibilities, systematizing hazard identification, and establishing continuous improvement cycles. However, the evidence also shows that the mere formal adoption of a system does not guarantee its effectiveness. X. Liu et al. (2023) identified major barriers to the effectiveness of ISO 45001 certification, including the lack of a preventive culture, limited internal commitment, and constraints in resources and competencies. Consistently, Podrecca et al. (2024) found that the adoption of ISO 45001 may be associated with improved organizational outcomes, but its impact depends on how it is operationalized within the company. From a performance perspective, Ghosh et al. (2024) showed that leading safety indicators are associated with better preventive conditions in construction projects, while Lingard et al. (2017) demonstrated the importance of temporally analyzing safety indicators to understand the actual evolution of preventive performance in complex projects.

Beyond its impact on prevention, safety management has also begun to be assessed from an economic perspective, since the absence of prevention entails direct and indirect costs associated with accidents, work interruptions, productivity losses, and regulatory exposure. Cagno et al. (2013) pointed out that economic evaluation in occupational safety and health constitutes a key component in assessing the convenience of preventive interventions, especially in small and medium-sized enterprises. Later, Grimani et al. (2018), in a systematic review from the employer’s perspective, concluded that the available evidence supports the usefulness of analyzing the cost-effectiveness and profitability of OSH interventions. At the organizational level, Arévalo Sarrate et al. (2024) and Podrecca et al. (2024) also suggest that management systems can generate benefits that go beyond accident reduction and include improvements in performance, productivity, and operational sustainability.

Despite these advances, an important gap remains in applied literature: studies that evaluate, within the same real-world high-risk construction case, the effect of OSHMS implementation on three simultaneous dimensions are still relatively scarce: system compliance, the redistribution of occupational risk levels, and the economic implications of the intervention. This gap is particularly evident in hospital projects involving specialized electrical, sanitary, and fire protection system installations, where work at height, excavations, lifting operations, hot work, and electrical exposure converge within the same operational environment. In this regard, the novelty of the present study lies in assessing, through a before-and-after design, how the structured implementation of an OSHMS in a highly complex hospital project in Casma, Peru, modifies not only the documentary and operational performance of the system, but also occupational risk and the economic balance of the intervention.

2. Methodology

2.1. Study design

The present study adopted a quantitative and applied approach, using a pre-experimental before-and-after design in a single intervention setting, aimed at evaluating the effect of implementing an OSHMS on system compliance, the reduction of occupational risk levels, and the economic implications in high-risk construction activities. This type of design is appropriate for the evaluation of preventive interventions in real occupational environments when the establishment of control groups or random assignments is not feasible, and it is particularly useful for analyzing operational changes derived from safety actions implemented directly in the field (Lehtola et al., 2008; Van Der Molen et al., 2016; Vitrano et al., 2023).

Methodologically, the study was structured into three sequential stages: (i) establishment of the baseline through an initial diagnostic assessment of the OSHMS and the occupational risk profile; (ii) design and implementation of the system under a continuous improvement approach; and (iii) post-implementation evaluation to compare changes in system compliance, risk classification, and economic outcomes. This before-and-after evaluation framework is consistent with the literature on occupational safety and health interventions, which emphasizes that the effectiveness of such actions depends not only on their formal implementation, but also on their design, contextualization, and systematic evaluation in dynamic settings such as construction projects (Dyreborg et al., 2024).

2.2. Project description and high-risk activities

The study was conducted in a highly complex hospital project located in Casma, Peru, during 2024. The operational setting included specialized activities associated with electrical installations, sanitary systems, and fire protection systems, carried out under real construction-site conditions and with simultaneous interaction among different work fronts. This type of environment involves high operational demands due to the coexistence of technical tasks, spatial constraints, interferences among specialties, and the need for continuous coordination, conditions that have been recognized as factors increasing hazard exposure in construction and assembly projects (Almaskati et al., 2024; Rashidi Nasab et al., 2023).

The activities evaluated included work at height, excavations, lifting operations, electrical work, and hot work, all of which were associated with significant hazards such as falls from different levels, electrical contact, struck-by-object incidents, line-of-fire exposure, fires, and overexertion. The selection of this study setting was methodologically appropriate, given that international evidence has shown these hazards to be among the most relevant in construction, both because of their frequency and their potential to cause serious or fatal injuries. Likewise, the simultaneous presence of critical tasks and multiple technical specialties reinforces the need for systematic occupational safety and health interventions, particularly in projects involving electrical installations, MEP components, and high-risk operational activities (Aneziris et al., 2012; Tripathi & Mittal, 2025).

In this context, the project represented a suitable case study for evaluating OSHMS implementation, as it combined conditions representative of high-risk construction with specialized processes requiring formal preventive controls, continuous supervision, and coordination mechanisms among activities. Therefore, the methodological evaluation focused on an environment where safety management was not only a regulatory requirement, but also a critical condition for maintaining operational continuity and reducing workers' exposure to relevant occupational risks (Newaz et al., 2025; Selleck et al., 2023).

2.3. Baseline assessment of the OSHMS

The study baseline was established through an initial diagnostic assessment of the OSHMS and the occupational risk profile present in the activities analyzed. For this purpose, three main sources of information were integrated: (i) documentary review of internal safety records, accident reports, inspections, and existing procedures; (ii) direct observation of field working conditions; and (iii) application of a baseline Hazard Identification, Risk Assessment, and Control (HIRAC) matrix for hazard identification and initial risk assessment. This approach made it possible to characterize the actual condition of the system prior to the intervention and to generate a comparable reference for the post-implementation evaluation, in line with recent studies highlighting the need for systematic baseline diagnoses and practical self-assessment or organizational assessment tools in occupational safety and health (Rantala et al., 2024).

The diagnostic assessment focused on two complementary dimensions. The first corresponded to the level of OSHMS compliance, evaluated based on documentary and operational evidence related to preventive planning, hazard identification, procedures for critical tasks, emergency preparedness, training, risk control, and system monitoring. The second corresponded to the characterization of the baseline occupational risk profile, constructed from hazard identification by activity and its classification according to severity and probability. This strategy made it possible not only to identify management gaps, but also to establish the initial distribution of risks against which the effect of implementation was evaluated, following an approach consistent with studies emphasizing that the effectiveness of OSH systems depends on the quality of the initial assessment and on the ability to translate it into concrete intervention priorities at the worksite (Sanni-Anibire et al., 2020).

2.4. OSHMS implementation framework

The implementation of the OSHMS was structured under the continuous improvement approach of the Plan–Do–Check–Act (PDCA) cycle, with the aim of translating baseline findings into an operational, documented, and assessable intervention. This framework made it possible to organize the methodological sequence of the intervention from initial planning to performance verification and system improvement, in line with contemporary approaches to the implementation of occupational safety and health management systems. The Plan phase included defining the scope of the system, formulating the safety policy and objectives, preparing the annual plan, updating the HIRAC matrix, preparing the internal regulations, and identifying control needs for critical tasks. The Do phase included the establishment of the occupational safety and health committee, the execution of training and inductions, the application of

procedures for high-risk work, the implementation of operational controls, and the deployment of the emergency plan (Kunodzia et al., 2024; Xu et al., 2024).

The Check phase involved periodic inspections, record tracking, monitoring of safety indicators, internal auditing, and risk reassessment, whereas the Act phase was focused on reviewing findings, defining corrective actions, and consolidating continuous improvement. This framework ensured that implementation was not limited to the documentary development of the system, but also incorporated effective field controls, supervision mechanisms, and feedback criteria to adjust the project's preventive performance (see Fig. 1).

2.5. Risk assessment and safety indicators

Occupational risk assessment was carried out based on the baseline HIRAC matrix and its subsequent update following OSHMS implementation. For each identified hazard, the risk level was estimated by combining two components: severity and probability. Severity represented the potential magnitude of harm in terms of consequences for worker safety and health, whereas probability reflected the likelihood of occurrence of the event as a function of expected frequency, exposure, and observed working conditions. This procedure is consistent with widely used approaches in occupational risk assessment, in which criticality is derived from the combination of expected consequence and likelihood of occurrence (Azadeh-Fard et al., 2015; R. Liu et al., 2023).

The risk level was calculated using the following expression:

$$NR = S * P$$

1

where NR is the risk level, S corresponds to severity, and P to probability. Severity was assessed using an ordinal six-level scale, ranging from minimal (1) to catastrophic (6), while probability was rated across five levels: very unlikely (1), unlikely (2), possible (4), likely (8), and very likely (16). Based on the multiplication of both components, risks were classified into three operational categories: low (1–9), moderate (10–30), and high (31–96). This classification scheme made it possible to prioritize intervention and define the need for additional controls or, where necessary, the temporary suspension of activities, in line with practical risk management criteria used in construction and OSH systems (Ledic Neto et al., 2024). Table 1 presents the risk classification criteria used in the HIRAC assessment.

Table 1
Risk level classification criteria used in the HIRAC assessment

Component	Value	Classification	Criterion
Severity (S)	1	Minimal	Incident or minor and temporary impact
	2	Minor	Minor accident or impact requiring short medical leave
	3	Moderate	Moderate temporary disabling accident
	4	Significant	Severe temporary disability
	5	Severe	Permanent disability or severe harm
	6	Catastrophic	Fatal accident or occupational illness
Probability (P)	1	Very unlikely	Remote event or not previously experienced
	2	Unlikely	May occur approximately once a year
	4	Possible	May occur once every 90 days or once per project
	8	Likely	May occur once every 30 days or twice per project
	16	Very likely	Repetitive event, at least once every 7 days or three times per project
Risk level	1–9	Low risk	The activity may continue under routine controls
	10–30	Moderate risk	Requires additional risk-reduction measures and monitoring
	31–96	High risk	The activity must be suspended until effective controls are implemented

As a complement to risk assessment, safety performance was analyzed through operational indicators calculated for the periods before and after implementation of OSHMS. For this purpose, hours worked (HH), the total number of recorded accidents, days lost due to accidents, and the percentage distribution of high, moderate, and low-risk conditions were used.

The frequency rate (FR) was estimated as the ratio between the number of accidents that occurred and the hours worked, multiplied by one million, according to the following expression:

$$FR = \frac{N_a * 10^6}{HH}$$

2

where N_a represents the number of accidents recorded during the period analyzed.

2.6. Statistical analysis and economic evaluation

The data obtained from the baseline and post-implementation assessment were processed using descriptive statistics and before-and-after comparative analysis. The level of OSHMS compliance was summarized through frequencies, scores, and percentages by dimension; additionally, the distribution of occupational risks was organized into low, moderate, and high categories, while safety indicators were calculated from monthly records of accidents and hours worked. This approach made it possible to describe both the condition of the system and the evolution of the project's risk profile and preventive performance (Wang et al., 2022).

To assess the variation in the distribution of risk levels before and after OSHMS implementation, Pearson's chi-square test was used, considering a significance level of α = 0.05. This test was applied to the contingency table constructed from the frequencies of risks classified as low, moderate, and high at both evaluation points. The choice of this procedure was since the variable analyzed was categorical and the objective was to determine whether the observed frequency distribution after the intervention differed significantly from the baseline. In addition, the results were interpreted together with the observed changes in frequency, severity, and accident rates, to integrate evidence on both potential risk and actual safety performance (Arévalo Sarrate et al., 2024).

The economic evaluation was conducted through a benefit–cost analysis. First, the unit cost associated with a minor accident was estimated, considering direct and indirect expenses such as transportation, non-worked time, medical leave, productivity compensation, and other operational costs. Second, the potential economic exposure associated with non-compliance with OSH regulations was estimated based on potential administrative penalties linked to system deficiencies. Finally, the estimated total economic benefit was obtained as the sum of savings from avoided accidents and reduced potential economic exposure, and it was compared with the total cost of OSHMS implementation using the following expression:

$$B/C = \frac{Totalbenefit}{Totalcost}$$

5

This procedure is consistent with the literature on economic evaluation in OSH, which recognizes the usefulness of benefit–cost analysis and ROI as tools for assessing the financial convenience of preventive interventions (Cagno et al., 2013).

3. Results

3.1. Baseline diagnosis of the OSHMS and occupational risk profile

To establish the OSHMS baseline, an initial diagnostic assessment was conducted in the project's high-risk construction activities. This assessment made it possible to identify the system's level of

compliance, recognize the main causes associated with the generation of occupational risks, and characterize the hazards with the highest frequency of occurrence in the analyzed setting.

Table 2 presents the initial level of OSHMS compliance by dimension. Overall compliance was 22.5%, revealing an incipient state of the system at the beginning of the study. The most critical gaps were concentrated in procedures for critical tasks, accident and incident investigation, and training and instruction, dimensions in which no compliance was recorded. In contrast, the occupational safety and health management dimension reached the highest relative value (71.4%), followed by emergency preparedness (50.0%). Nevertheless, these results were still insufficient to sustain adequate preventive performance in an environment characterized by activities with high occupational exposure.

Table 2
Initial diagnosis of OSHMS compliance by dimension at baseline

Dimension	Items evaluated	Items complied with	Score obtained	Maximum score	Compliance (%)
Occupational safety and health management	7	5	15	21	71.40
Hazard identification and risk assessment	3	1	3	9	33.33
Procedures for critical tasks	4	0	0	12	0.00
Accident and incident investigation	4	0	0	12	0.00
Emergency preparedness	4	2	6	12	50.00
Training and instruction	4	0	0	12	0.00
Personal protective equipment (PPE)	3	1	3	9	33.33
Occupational safety and health control	3	1	3	9	33.33
Communication and promotion	4	1	3	12	25.00
Risk control	4	1	3	12	25.00
Total	**40**	**12**	**36**	**160**	**22.50**

The causality analysis summarized in Fig. 2 showed that the main sources generating risk were concentrated in three factors: limitations in OSH training (n = 8; 27%), deficient implementation of standard operating procedures (n = 6; 20%), and inadequate use of personal protective equipment (n = 4; 13%). Together, these three categories accounted for 60% of the recorded causes, indicating that the

system's initial weaknesses were mainly located in preventive training, safe-work standardization, and the control of operational behavior. The cumulative line in the Pareto diagram further shows that, when limited hazard awareness and a weak preventive culture are added, 80% of the causes are reached, thereby defining a priority intervention zone for OSHMS implementation.

On the other hand, the initial distribution of occupational risks, presented in Fig. 3, showed that overexertion was the most frequent event (18.6%; n = 19), followed by falls from height (13.7%; n = 14) and same-level falls (10.8%; n = 11). A second group in terms of importance included crushing and exposure to line-of-fire hazards (both 8.8%; n = 9), as well as direct and indirect contact with electric current (7.8%; n = 8). This pattern shows that the baseline was dominated by a combination of ergonomic, locational, mechanical, and electrical risks, characteristic of construction environments with multiple work fronts and simultaneous critical tasks. Taken together, these results confirmed that the project presented high occupational exposure and justified the need for a structured intervention aimed at strengthening the management system and specifically controlling the most recurrent hazards.

3.2. Design and implementation of the occupational safety and health management system

Based on the findings obtained from the initial diagnosis, an OSHMS was designed and implemented to reduce exposure to occupational risks in high-risk construction activities. The system was structured in accordance with current Peruvian occupational safety and health regulations and organized under the PDCA continuous improvement cycle, to ensure the planning, execution, monitoring, and systematic improvement of the preventive measures adopted.

The intervention focused on the project's critical activities, particularly electrical installations, sanitary systems, and fire protection systems, because these areas involved tasks with greater damage potential, such as work at height, excavations, lifting operations, hot work, and electrical work. In this context, the OSHMS was conceived as an integrated intervention that articulated documentary, technical, organizational, and operational components.

Table 3 summarizes the main components incorporated into the OSHMS. Among the most relevant elements were the formulation of the safety and health policy, the preparation of the annual plan, the updating of the HIRAC matrix, the formalization of the internal regulations, the standardization of procedures for critical tasks, the deployment of the training program, the implementation of the emergency plan, the scheduling of periodic inspections, and the internal audit of the system. Taken together, these components strengthened the organization's preventive structure and made it possible to align project operations with a systematic risk-control approach.

Table 3
Components implemented in the occupational safety and health management system

OSHMS component	Description of implementation	Main purpose
Safety, occupational health, environment, and quality policy	An integrated SHEQ policy was formulated and approved in line with current regulations and communicated to project personnel	To establish institutional commitment to risk prevention and continuous improvement
Annual OSH plan	A work plan was prepared with scheduled activities for planning, implementation, monitoring, and system evaluation	To organize preventive and corrective OSHMS actions
HIRAC matrix	Hazards were identified, risks were assessed, and controls were defined by process, position, and critical activity	To prioritize risks and establish operational controls
Internal OSH regulations	Internal regulations were prepared and formalized, including rules, responsibilities, and disciplinary measures in OSH matters	To regulate preventive behavior and regulatory compliance
Procedures for high-risk tasks	Specific guidelines were established for work at height, electrical work, hot work, and other critical activities	To standardize the safe execution of high-risk tasks
Training and awareness program	Inductions, daily toolbox talks, weekly meetings, and scheduled OSH training sessions were implemented	To strengthen preventive competencies and safety culture
Emergency and contingency plan	Response protocols, brigades, communication flowcharts, and emergency actions were designed	To improve preparedness and response to critical incidents
Inspection program	Periodic inspections were scheduled for safety conditions, equipment, working conditions, and compliance with controls	To detect deviations and correct unsafe conditions
Incident investigation and corrective actions	Procedures were established to record, investigate, and correct incidents and non-conformities	To prevent recurrence of undesired events and strengthen organizational learning
Internal OSHMS audit	The internal audit of the system was planned and executed, with follow-up on findings and improvement actions	To verify the degree of implementation and effectiveness of the system
PPE and collective protective equipment control	Delivery, use, inspection, and replacement of personal and collective protective equipment were strengthened	To reduce direct exposure to existing hazards

The implementation of the system was carried out sequentially during the intervention period. In the first phase, planning actions were executed, including the initial compliance analysis, definition of scope, formulation of the OSH policy, preparation of the general schedule, and design of control instruments.

Subsequently, during the execution phase, the occupational safety and health committee was established, corrective measures derived from the initial diagnosis were applied, operational controls were reinforced, and awareness and training activities were delivered to operational and technical personnel. Finally, during the verification and improvement phase, monitoring, inspections, internal audits, and management review of the system were conducted.

In addition to the documentary component, the intervention incorporated operational management mechanisms in the field. In this regard, functional responsibilities were defined for management personnel, technicians, SSOMA supervisors, warehouse staff, and operational workers, with emphasis on compliance with procedures, authorization of high-risk work, verification of PPE use, development of job safety analyses (JSA), incident reporting, and participation in training and inspection activities. In the context of this article, these responsibilities are understood as part of the OSHMS governance framework, whose purpose was to ensure the effective application of the defined controls.

Personnel training and awareness constituted one of the central pillars of the implementation. For this purpose, a program was developed that included mandatory induction for new personnel, short pre-task talks, weekly safety meetings, thematic training on critical risks, and awareness activities on OSH and the environment. These actions were aimed at correcting one of the main gaps identified in the baseline: the insufficiency of effective and up-to-date training. In this way, training ceased to be an isolated activity and became integrated into operational control and the strengthening of preventive culture.

In parallel, emergency preparedness and response measures were implemented through the participatory development of the contingency plan, the establishment of response protocols, and the definition of the communication flowchart for critical events. This component was especially relevant in an environment exposed to electrical hazards, fires, gas leaks, falls, and other potentially severe situations. The incorporation of the emergency plan into the OSHMS made it possible to integrate prevention with organized response capacity for incidents. Table 4 summarizes the main operational actions implemented for risk control, grouped according to the intervention logic of the system.

Table 4
Main actions implemented for operational risk control

Intervention line	Implemented action	Outcome
Documentary management	Preparation of the policy, annual plan, internal regulations, HIRAC, procedures, and records	System formalization and traceability
Organizational management	Establishment of the OSH committee and assignment of OSH responsibilities	Strengthening of system governance
Training and awareness	Inductions, daily talks, scheduled training, and weekly meetings	Improvement in competence and preventive behavior
Operational control	Implementation of JSA, work permits, signage, inspections, and controls for critical tasks	Reduction of unsafe acts and conditions
Emergency preparedness	Preparation of the emergency plan, brigades, and response protocols	Timely and coordinated incident response
Verification and improvement	Monitoring, internal audits, incident investigation, and corrective actions	Performance evaluation and continuous improvement

From a methodological perspective, the intervention was not limited to the generation of management documents but also incorporated concrete field controls. Among the measures applied were the preparation of JSAs prior to the start of activities, the requirement of permits for high-risk work, supervision of proper PPE use, signage of critical areas, periodic inspection of equipment and tools, and the adoption of corrective measures derived from inspection and audit findings. These actions sought to reduce the gap between formal compliance and actual on-site performance.

As an intermediate result, the system evolved from an initial condition marked by documentary, procedural, and training deficiencies toward a more organized and functional management structure. In operational terms, the company succeeded in providing basic tools for preventive management, strengthening field supervision capacity, and establishing mechanisms for control, monitoring, and improvement of occupational safety and health performance.

3.3. Change in OSHMS compliance, risk level, and safety indicators after implementation

To evaluate the effect of OSHMS implementation, the baseline condition was compared with the post-intervention condition, considering three analytical dimensions: (i) the level of system compliance, (ii) the distribution of occupational risk levels, and (iii) the project's safety indicators. Overall, the results showed a substantial improvement in both the preventive management structure and the operational control of risks present in high-risk construction activities.

First, the final diagnostic assessment revealed a significant increase in the level of OSHMS compliance. Whereas the system achieved an overall compliance level of 22.5% at baseline, this value rose to 79.0%

after implementation, representing an absolute increase of 56.5 percentage points. Figure 4 shows that the greatest improvements were recorded in training and capacity building, accident and incident investigation, and procedures for critical tasks, all of which increased from 0.0% to 75.0%. Similarly, communication and promotion and risk control increased by 50.0 percentage points, while the occupational safety and health management dimension reached 100.0% compliance, becoming the best-performing final dimension. These results indicate that the intervention significantly strengthened the documentary, operational, and monitoring components of the system (see Fig. 4).

The improvement of the system was also reflected in the final audit, which rated OSHMS performance as very good, in contrast to the deficient condition observed at baseline. From a management perspective, this change suggests that the organization evolved from a fragmented and predominantly reactive preventive scheme toward a more structured model, with formal instruments, defined operational controls, and more consistent monitoring mechanisms.

Second, the comparative analysis of the risk profile revealed a substantial reduction in the criticality of occupational exposure. Before implementation, the distribution of risks was concentrated in the moderate and high categories, which together accounted for 84% of the total identified. After the intervention, the risk structure changed markedly: high risks decreased from 41% to 0%, low risks increased from 16% to 61%, and moderate risks decreased from 43% to 39%. Table 5 summarizes this comparison.

Table 5
Comparison of risk levels before and after OSHMS implementation

Risk level	Before implementation (n)	Before implementation (%)	After implementation (n)	After implementation (%)	Absolute change (percentage points)
Low	16	16	62	61	+ 45
Moderate	44	43	40	39	-4
High	42	41	0	0	-41
Total	**102**	**100**	**102**	**100**	**-**

In disaggregated terms, before implementation, the 16 low risks corresponded entirely to electrical maintenance work; the 44 moderate risks included 42 in electrical maintenance work, 1 in emergency, and 1 in environment, whereas the 42 high risks comprised 34 in electrical maintenance work and 8 in emergency. After implementation, the 62 low risks were distributed as 60 in electrical maintenance work, 1 in emergency, and 1 in environment; the 40 moderate risks corresponded to 32 in electrical maintenance work and 8 in emergency; and no high risks were recorded in any category. This shift toward lower criticality levels constitutes one of the most relevant findings of the study, as it indicates that the implemented measures effectively intervened on the hazards with the highest severity and probability.

The observed reduction suggests that a substantial proportion of the risks initially classified as high or moderate were mitigated through the application of engineering controls, administrative controls, signage, specific training, operational supervision, and strengthened use of personal protective equipment. In practical terms, this reflects a real improvement in work control conditions, beyond the documentary compliance of the system.

As a complement, OSHMS implementation was also associated with an improvement in the project's safety indicators. Before the intervention, four minor accidents were recorded during the evaluation period, whereas after implementation, one minor accident was recorded. In neither period were disabling or fatal accidents reported. Likewise, cumulative hours worked amounted to 100,500 HH before implementation and 104,200 HH after implementation. Based on these records, the cumulative frequency rate decreased from 39.80 to 9.60, which is equivalent to an approximate reduction of 75.9%. Since no lost days due to accidents were recorded in either period, the cumulative severity rate and cumulative accident rate remained at 0.00. Table 6 summarizes these results.

Table 6
Comparison of safety indicators before and after OSHMS implementation

Indicator	Before implementation	After implementation	Variation
Cumulative hours worked	100,500	104,200	+ 3,700
Minor accidents (n)	4	1	-3
Total accidents (n)	4	1	3
Cumulative frequency rate (FR)	39.80	9.60	-30.20
High risks (%)	41	0	-41
Moderate risks (%)	43	39	-4
Low risks (%)	16	61	+ 45

Taken together, these results reinforce the evidence of improved preventive performance in the project, as they show a simultaneous reduction in the occurrence of minor accidents, in the cumulative frequency rate, and in the proportion of high risks. Although the severity rate showed no variation due to the absence of lost days, the decrease in the frequency rate and the elimination of high risks suggest a favorable response to the implemented system in terms of operational safety.

From a statistical standpoint, the association between OSHMS implementation and the reduction in risk levels was assessed using Pearson's chi-square test. The results showed a value of χ^2=69.319, with 2 degrees of freedom and a p-value < 0.001, indicating a statistically significant difference in the distribution of risk levels before and after implementation. Consistently, the likelihood ratio was also significant (87.387, df = 2, p < 0.001). Consequently, the null hypothesis was rejected, and it was concluded that OSHMS implementation was associated with a significant reduction in occupational risks in the project evaluated (Table 7).

Table 7
Chi-square test results for comparing risk levels before and after implementation

Statistical test	Value	df	p-value	Interpretation
Pearson's chi-square	69.319	2	< 0.001	There is a statistically significant difference in the distribution of risk levels before and after OSHMS implementation
Likelihood ratio	87.387	2	< 0.001	

3.4. Economic implications of OSHMS implementation

The implementation of the Occupational Safety and Health Management System (OSHMS) generated favorable economic implications for the organization, both through the reduction of occupational accidents and through the decrease in economic exposure associated with regulatory non-compliance. To evaluate this effect, three components were considered: (i) the savings derived from the reduction in minor accidents, (ii) the reduced potential economic exposure resulting from compliance with occupational safety and health regulations, and (iii) the total cost of implementing the system. Based on these elements, the total economic benefit and the benefit–cost ratio of the intervention were estimated.

Table 8 shows that the most important economic component corresponded to avoided costs associated with regulatory compliance, with a subtotal of S/ 1,122,700.00, a value considerably higher than the direct savings associated with accident reduction. Within this component, the absence of an implemented and sustained OSHMS, the lack of preventive measures against occupational risks, the occurrence of accidents derived from regulatory non-compliance, and the omission of occupational medical examinations each represented a potential exposure of S/ 139,050.00. In contrast, the direct savings from the reduction of occupational accidents were smaller in magnitude and were estimated at S/ 870.00 per minor accident avoided, integrating transportation costs, administrative support, lost wages, medical leave, compensatory overtime, and other indirect costs. Taken together, these results indicate that the economic benefit of the OSHMS was not concentrated solely on the reduction of accident events, but mainly on decreasing the financial vulnerability associated with legal non-compliance.

Table 8
Estimated economic benefits of OSHMS implementation

Component	Subcomponent	Amount (S/.)
Savings from reduction of occupational accidents	Transportation of the injured worker (round trip)	70.00
	Administrative support	30.00
	Lost wages of the injured worker	30.00
	Subsidized days due to medical leave	240.00
	Overtime to compensate for productivity loss	300.00
	Other associated indirect costs	200.00
	Subtotal savings from 1 avoided accident	**870.00**
Avoided costs due to regulatory compliance	Absence of an implemented and sustained OSHMS	139,050.00
	Lack of measures for vulnerable workers	25,750.00
	Lack of preventive measures against occupational risks	139,050.00
	Absence of a HIRAC matrix	77,250.00
	Accidents resulting from regulatory non-compliance	139,050.00
	Omission of occupational medical examinations	139,050.00
	Lack of mandatory OSH records	77,250.00
	Absence of an annual OSH plan	77,250.00
	Non-compliance with control of occupational agents	77,250.00
	Absence of first aid and fire prevention measures	77,250.00
	Lack of an OSH committee	77,250.00
	Failure to conduct OSHMS audits	77,250.00
	Subtotal avoided penalties	**1,122,700.00**
Estimated total economic benefit	**Avoided accident costs + avoided penalties**	**1,123,570.00**

Table 9 shows that the total cost of OSHMS implementation amounted to S/ 276,000.00, mainly distributed across activities related to the prevention of occupational diseases (S/ 80,000.00),

measurement, monitoring, and review of system performance (S/ 65,000.00), actions to reduce occupational incidents and accidents (S/ 55,500.00), and measures to reduce losses in emergency situations (S/ 55,000.00). This cost structure shows that the largest share of the investment was allocated to sustained prevention and performance-control components rather than to isolated documentary implementation activities. When these costs were compared with the estimated total economic benefit of S/ 1,123,570.00, the estimated net benefit was S/ 847,570.00, and the benefit–cost ratio was 4.07, indicating that for every sol invested in OSHMS implementation, the organization obtained an estimated economic return of S/ 4.07. This result supports the economic feasibility of the intervention and shows that preventive management can also generate financial value in high-risk construction projects.

Table 9
OSHMS implementation costs and economic profitability indicators

Dimension	Activity	Amount (S/.)
OSHMS implementation cost	Hazard identification, risk assessment, and operational controls	5,500.00
	Verification of applicable legal requirements	4,000.00
	Internal communication of the management system	5,000.00
	Staff training and awareness	6,000.00
	Actions to reduce occupational incidents and accidents	55,500.00
	Actions to prevent occupational diseases	80,000.00
	Measures to reduce losses in emergencies	55,000.00
	Measurement, monitoring, and review of OSHMS performance	65,000.00
	Total implementation cost	**276,000.00**
Economic indicators	Estimated total economic benefit	1,123,570.00
	Estimated net benefit (benefit − cost)	847,570.00
	Benefit–cost ratio (B/C)	4.07
	Return per sol invested	S/. 4.07

Figure 5 visually reinforces this interpretation by showing the marked difference between the estimated total economic benefit and the total implementation cost. The length of the bar corresponding to the benefit shows that the potential returns of the system substantially exceeded the investment required for its implementation. Likewise, the summary box in the figure makes it possible to identify two key findings immediately: a benefit–cost ratio greater than 1, confirming the economic convenience of

implementation, and a positive net benefit, indicating that the expected benefits significantly exceeded the expenditure incurred. In interpretative terms, the figure shows that the OSHMS not only acted as a prevention and control tool, but also as a mechanism of economic protection against operational losses and regulatory contingencies.

However, these findings should be interpreted with caution. A substantial part of the estimated economic benefit came from potentially avoided costs associated with regulatory compliance; therefore, the result mainly reflects a reduction in financial exposure rather than necessarily an already materialized accounting saving. Even so, the analysis shows that OSHMS implementation was economically favorable and that its effects extended beyond improved safety performance by also strengthening the project's operational and financial sustainability.

4. Discussion

The results of this study show that OSHMS implementation was associated with a substantial improvement in the level of system compliance, which increased from 22.5% at baseline to 79.0% after the intervention. The greatest advances were concentrated in procedures for critical tasks, accident and incident investigation, training and capacity building, as well as communication and risk control. This pattern is consistent with the literature indicating that safety management systems generate more consistent effects when they cease to operate merely as documentary frameworks and become effectively integrated into the operational dynamics of the worksite. In the construction sector, Yoon et al. (2013) documented reductions in occupational injury rates in organizations with OHSMS, while Arévalo Sarrate et al. (2024) reported improvements in accident indicators when preventive management is implemented in a structured manner. Likewise, X. Liu et al. (2023) warned that one of the main limitations of these systems lies in the gap between formal certification and their actual field application. Considering these antecedents, the findings of the present study suggest that this gap may have been reduced through the incorporation of specific procedures, systematic training, operational supervision, and continuous monitoring mechanisms. This interpretation is also consistent with the findings of Navarro Claro et al. (2025), who showed that the maturity of safety systems can translate into better performance, sustainability, and organizational control outcomes in construction companies.

Regarding the risk profile, the reduction in high risks from 41% to 0% and the increase in low risks from 16% to 61% indicate that the intervention not only improved formal system compliance, but also tangibly modified the criticality of occupational exposure. This result is relevant because the effectiveness of an OSH system should not be assessed solely by the degree of documentary conformity, but also by its ability to transform actual working conditions and reduce the probability of severe events. In this regard, Arévalo Sarrate et al. (2024) argued that management systems are more useful when accompanied by quantitative monitoring of accident rates, whereas Golabchi et al. (2024) highlighted the need to integrate leading indicators with risk management to assess preventive performance more comprehensively. Similarly, Ghosh et al. (2024) found that better leading indicators are associated with better safety outcomes in construction projects, and Alruqi and Hallowell (2019) demonstrated that management

indicators are related to injury rates. Under this logic, the reduction in minor accidents from four to one, together with the decrease in the cumulative frequency rate from 39.80 to 9.60, reinforces the idea that the combination of HIRAC, procedures for critical tasks, job safety analyses (JSA), work permits, PPE control, inspections, and operational feedback can translate into a real reduction in hazard exposure and a verifiable improvement in preventive performance.

From an organizational and economic perspective, a benefit–cost ratio greater than 4 suggests that OSHMS implementation was not only preventively effective, but also economically justifiable in a high-risk construction environment. This finding is consistent with research recognizing that occupational safety and health can generate value beyond the immediate prevention of accidents by reducing operational interruptions, productivity losses, and vulnerability to regulatory contingencies. In particular, Navarro Claro et al. (2025) showed that the impact of OHSMS in the construction sector extends to human talent management and organizational performance, which reinforces the idea that these systems can positively influence the overall efficiency of the project and not only conventional safety indicators. Similarly, Podrecca et al. (2024) found that ISO 45001 adoption is associated with higher levels of productivity and profitability compared with non-adopting organizations. In this sense, the results obtained here provide applied evidence that a structured implementation of the OSHMS can simultaneously improve system compliance, risk redistribution, safety performance, and the economic rationality of preventive management in complex construction projects. However, these results should be interpreted with caution, given that an important part of the estimated economic benefit came from potential avoided costs due to regulatory compliance; therefore, the main contribution of the study lies in demonstrating the operational feasibility and organizational convenience of a well-implemented management system in a real context of high-risk exposure.

5. Conclusion

The results of the study show that the implementation of the OSHMS was associated with substantial improvements in the preventive performance of the project evaluated. Overall system compliance increased from 22.5% to 79.0%, with particularly relevant advances in procedures for critical tasks, accident and incident investigation, training, and risk control. At the same time, the risk profile showed a favorable redistribution, characterized by the elimination of high risks, the increase in low risks, and the reduction in minor accidents and the cumulative frequency rate. Taking together, these findings indicate that the intervention not only strengthened the documentary and organizational structure of the OSHMS but also produced tangible operational effects on risk exposure and safety performance. In addition, the economic evaluation showed a benefit–cost ratio greater than 4, suggesting that system implementation was not only preventively effective, but also economically advantageous in a high-risk construction environment.

However, the results should be interpreted considering certain limitations. The study was conducted in a single project and under a before-and-after design without a control group, which restricts the generalizability of the findings to other construction or business contexts. Likewise, an important part of

the estimated economic benefit came from potential avoided costs due to regulatory compliance; therefore, this component should be understood as an approximation of the preventive value of the system rather than as directly realized accounting savings. Even so, the study offers relevant practical implications, as it shows that a structured implementation of the OSHMS can simultaneously improve system compliance, risk criticality, and operational performance. Future studies should expand this approach through multi-case designs, longer follow-up periods, and the incorporation of additional indicators, such as safety culture, organizational climate, productivity, and cost-effectiveness across different types of construction projects.

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Figures

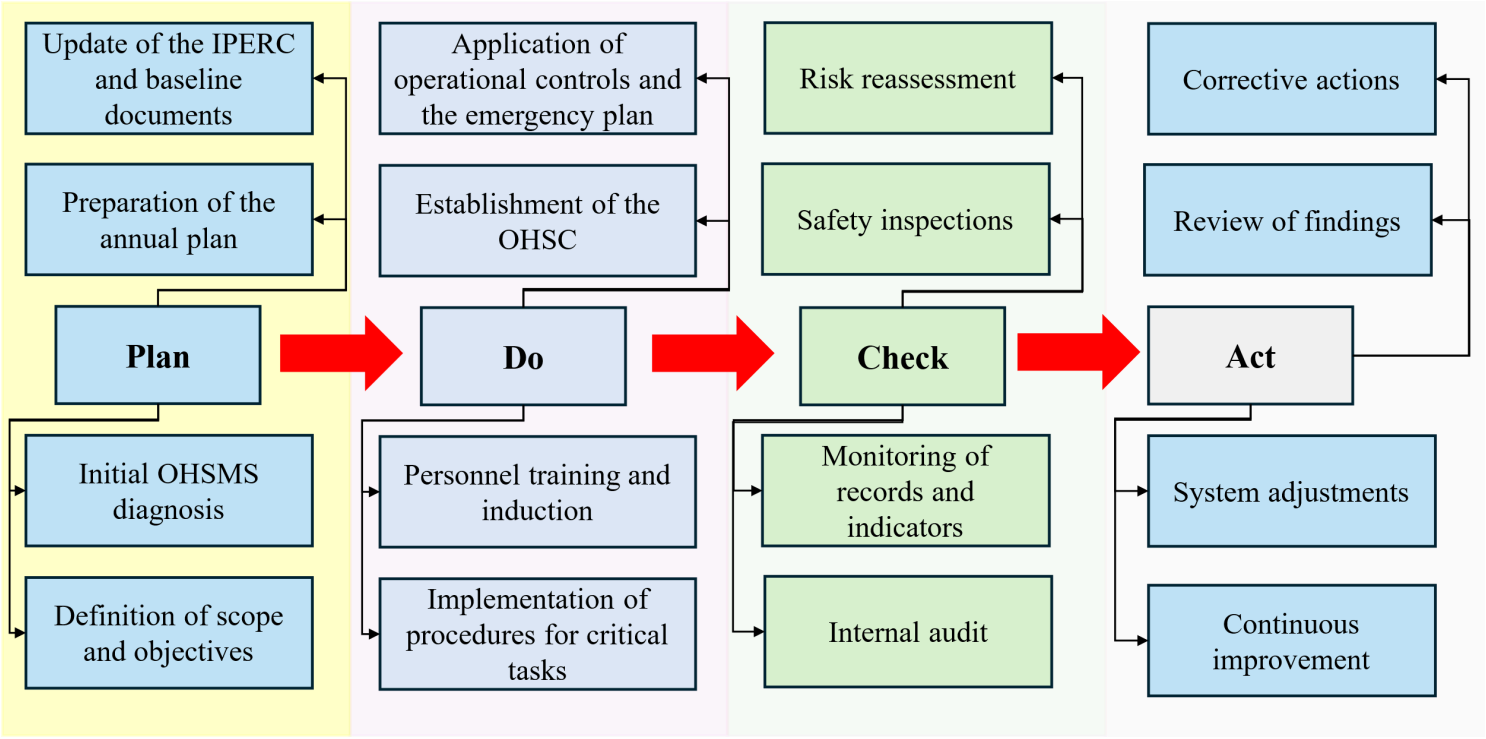


Figure 1

Methodological framework for implementation of OSHMS under the PDCA cycle

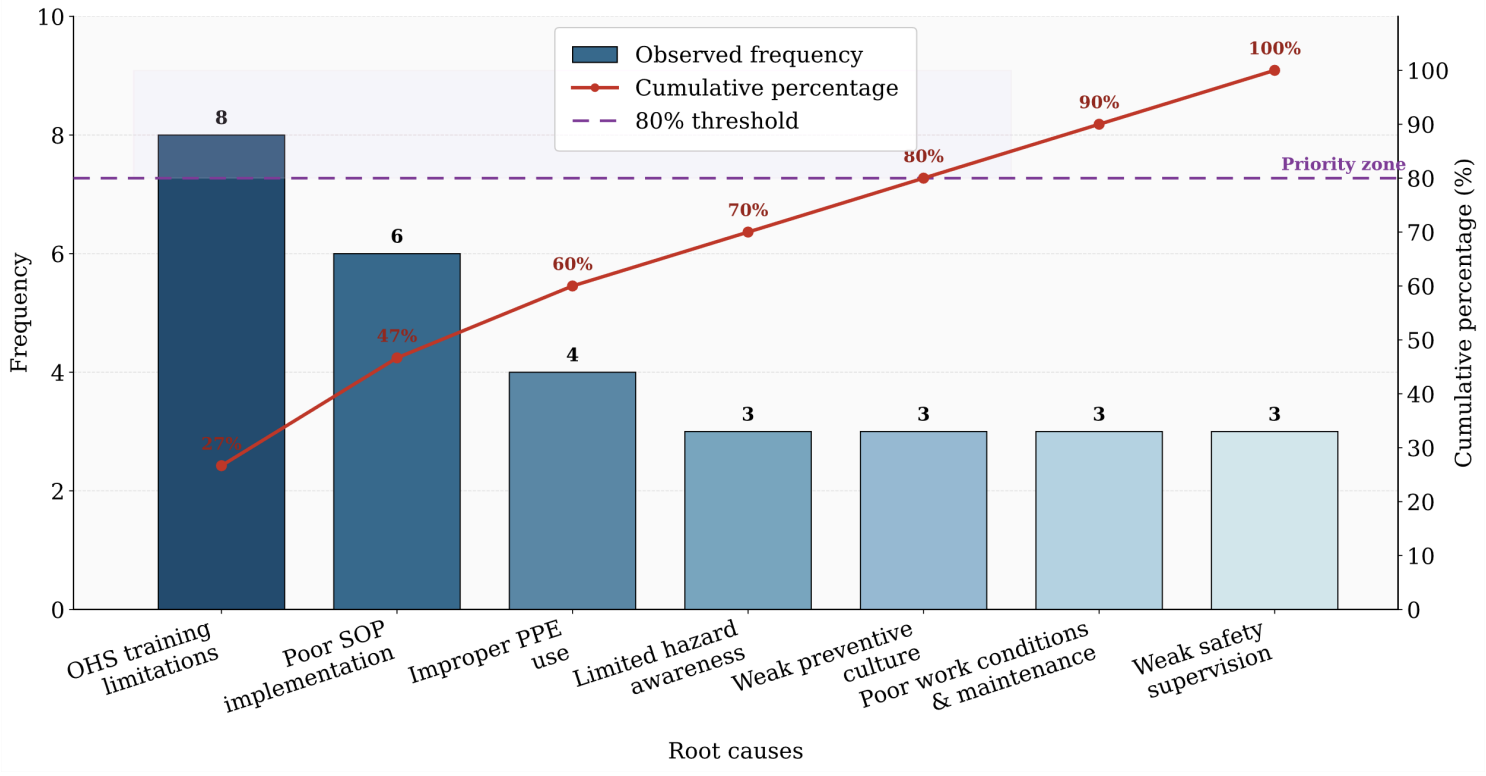


Figure 2

Pareto chart of the main causes associated with occupational risks at baseline

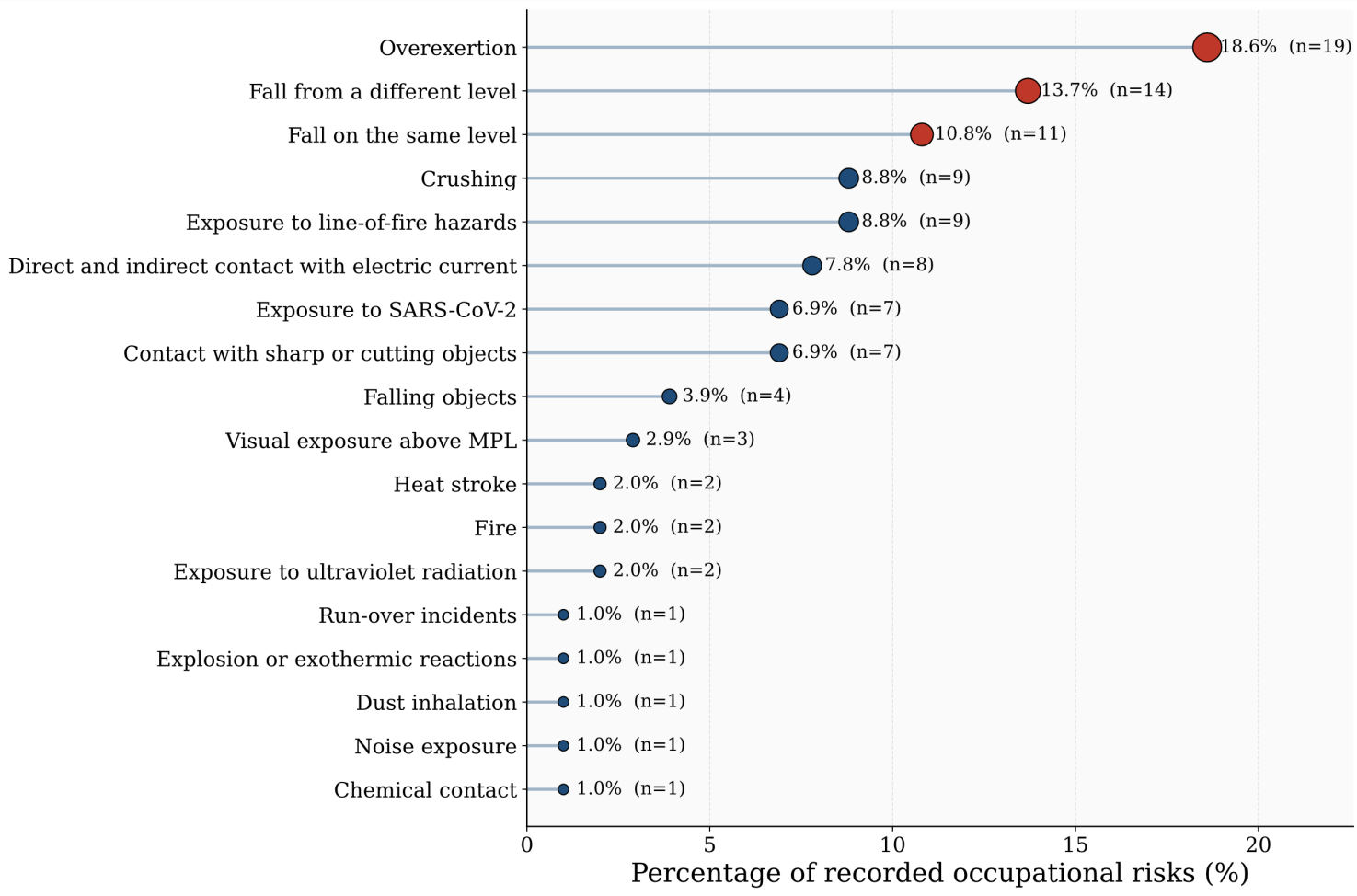


Figure 3

Occupational risks identified at baseline

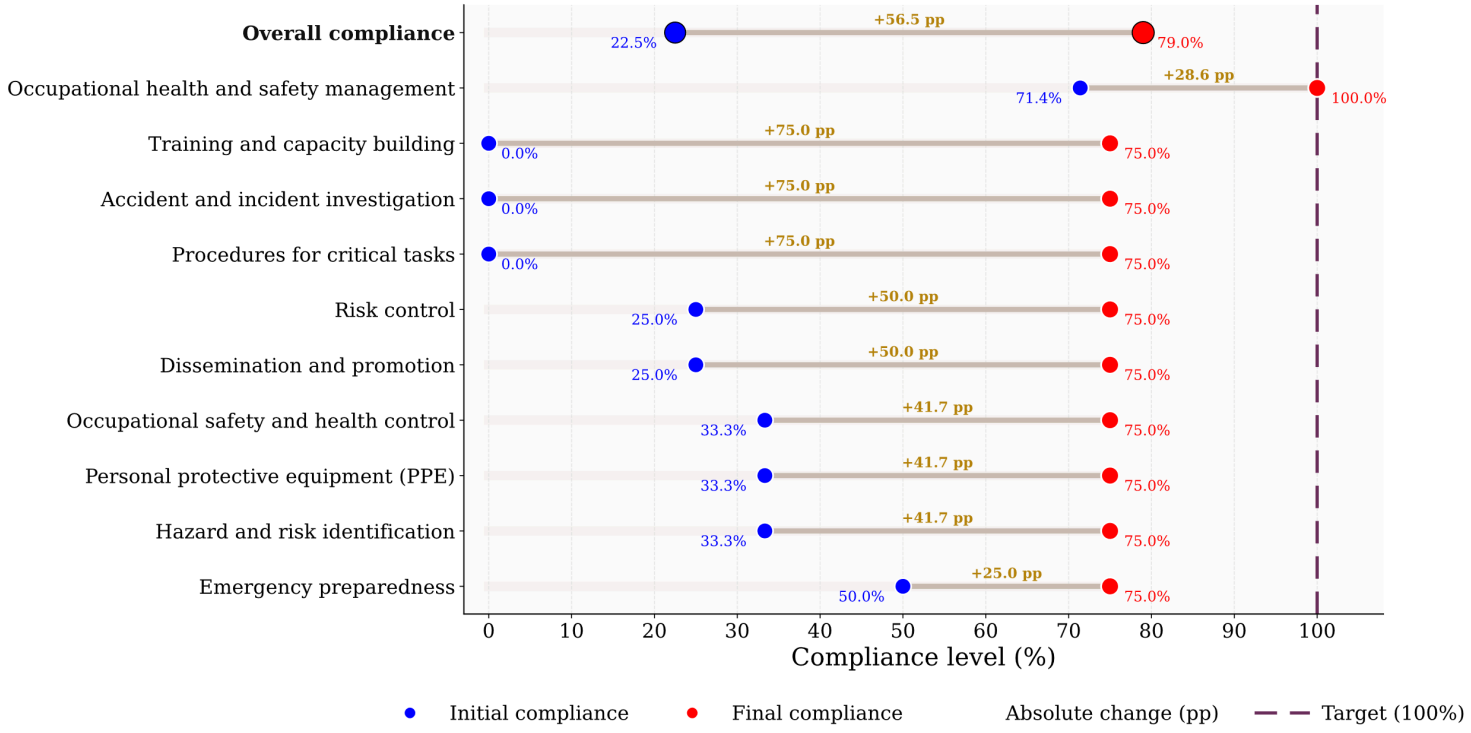


Figure 4

Comparison of OSHMS compliance before and after implementation

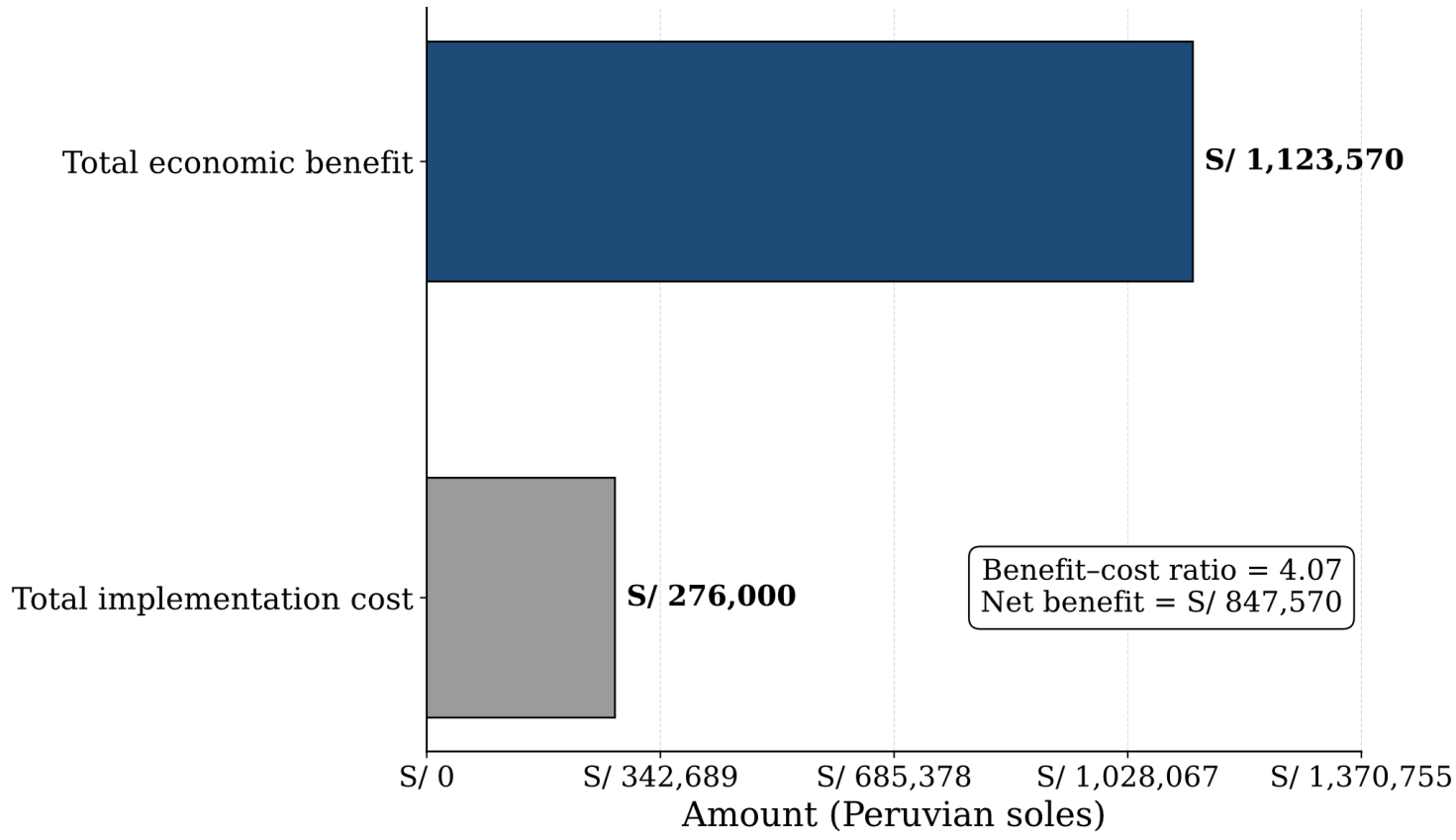


Figure 5

Economic effect of OSHMS implementation