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An Integrated JSA-SIMOPS Decision Support Framework for Intelligent Permit to Work Management in Heavy Industry: A Case Study of an Algerian Steel Complex

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Highlights:

1. Unified mathematical formulation that links the JSA risk index, the SIMOPS compatibility function, and a four state Permit to Work decision algorithm.
2. Risk Reduction Efficiency (RRE) indicator that quantifies the proportion of risk eliminated by current controls and provides a transparent acceptance criterion.
3. The framework on a real industrial site Algerian steel complex through seven representative work activities and three SIMOPS scenarios.

Abstract

Occupational accidents in heavy industry remain a persistent global concern, with the simultaneous execution of incompatible activities being a documented root cause of major incidents. The conventional Permit to Work (PTW) system, although widely adopted, suffers from manual coordination delays, fragmented information flows, and the inability to systematically detect hazardous interactions between Simultaneous Operations. This paper proposes an integrated decision support framework that unifies Job Safety Analysis (JSA), Simultaneous Operations (SIMOPS) compatibility evaluation, and a rule-based decision engine into an Intelligent Permit to Work (IPTW) architecture. The framework formalizes risk evaluation through a 5×5 risk matrix, computes a Risk Reduction Efficiency (RRE) index for each work activity, and embeds a quantitative SIMOPS compatibility function that classifies concurrent task pairs as Compatible, Conditionally Compatible, or Incompatible. A four-state decision algorithm GRANT, CONDITIONAL GRANT, DEFER, DENY translates these inputs into actionable permit outcomes. The framework is validated on an Algerian steel complex through seven representative work activities (lifting, 2 categories of hot work, radiography, painting, pressure testing, and work at height) and three SIMOPS scenarios. Results demonstrate an average RRE of 75.4% across the seven activities, identification of one strictly incompatible task pair (hot work × radiography), one conditionally compatible pair (hot work × cold work), and one fully compatible pair (cold work × lifting). The proposed IPTW framework provides a transparent, auditable, and replicable decision support layer suitable for deployment in steelmaking, oil and gas, and other multi-contractor industrial environments.

Keywords: Job Safety Analysis (JSA); Simultaneous Operations (SIMOPS); Intelligent Permit to Work; Occupational risk assessment; Decision support framework; Steel industry; Risk Reduction Efficiency.

1. Introduction

High risk sectors such as iron and steel, mining, petrochemical, and oil and gas industries experience a substantial burden of occupational injuries due to complex processes, hazardous materials, and concurrent operations. Globally, approximately 374 million non-fatal occupational injuries are recorded annually (ILO, 2023). Recent research highlights both the magnitude of this problem and the emergence of technical, organizational, and digital tools aimed at improving risk management and accident prevention.

Workers in the iron and steel industry exhibit a particularly high prevalence of occupational injuries, with an estimated 28–55% of workers affected over a 12 month period. The risk is notably higher among night shift workers and those who do not use personal protective equipment (Shabani et al., 2024; Rajak et al., 2021). Commonly reported injuries include cuts, fractures, and burns, while factors such as low educational level, work in high-risk areas, and insufficient safety knowledge have been identified as key predictors (Rajak et al., 2021). These findings underscore the importance of both technical controls and a strong safety culture in heavy industry (Shabani et al., 2024; Rajak et al., 2021).

Investigations of major industrial accidents, including Piper Alpha (1988), Texas City (2005), and Buncefield (2005), have consistently identified failures in permit coordination and the management of simultaneous operations (SIMOPS) as critical contributing factors.

Robust occupational health and safety management systems are associated with reduced accident rates, although their effectiveness is partly mediated by workers' safety knowledge and training (Liu et al., 2020). A comprehensive review of safety interventions indicates that engineering controls and organizational-level measures are generally more effective than isolated behavioral interventions or training alone, particularly when they do not rely on workers' discretionary compliance (Dyreborg et al., 2022). Multifaceted approaches that integrate technical solutions, management practices, training, and safety climate initiatives tend to yield the most significant and sustained reductions in injury rates (Liu et al., 2020; Dyreborg et al., 2022).

Job Safety Analysis (JSA) remains a fundamental method for hazard identification; however, it has been criticized for being time-consuming and for inadequately capturing interactions between concurrent tasks. Recent studies have proposed extended, multi-step, and relationship oriented JSA frameworks to address surrounding activities and simultaneous operations (Kwon et al., 2024; Ghasemi et al., 2023; Li et al., 2018). In parallel, digital and IoT-enabled systems are being developed, including intelligent safety platforms for dynamic monitoring of plant and worker hazards (Gnoni et al., 2020), digital permit-to-work (PTW) systems (Chen et al., 2023; Fasasi et al., 2022), and AI-supported SIMOPS visualization tools for large-scale oil and gas projects (Kwon et al., 2024; Kannan & Siddiqui, 2018; Gawargy et al., 2025). These approaches aim to enhance real-time risk awareness, compliance, and coordination in complex, multi-activity environments.

The aim of this study is to bridge the gap between JSA, SIMOPS, and operational PTW decision-making through the development of a structured Intelligent Permit to Work (IPTW) framework. The remainder of this paper is organized as follows: Section 2 reviews the relevant literature on JSA, SIMOPS, and PTW digitalization; Section 3 presents the proposed IPTW framework, including the risk scoring scheme, compatibility function, and decision algorithm; Section 4 describes the case study site and data collection procedures; Section 5 presents the results obtained from the Algerian complex; Section 6 discusses the operational implications and limitations of the framework; and Section 7 concludes the paper and outlines directions for future research.

2. Literature Review

Occupational risk management in heavy industry relies on multiple methods: task level analyses (e.g. JSA), process/system methods (e.g. HAZOP, FMEA, bow-tie), SIMOPS practices, and PTW systems. The papers below support this multi-layer picture and highlight where integration is still limited.

2.1 Occupational Risk Assessment in Heavy Industry

Structured risk assessment in industrial environments typically combines JSA, FMEA, HAZOP, FTA and bow-tie to cover task, equipment and system levels (Sharma & Tiwari, 2025; Pratama et al., 2025; Rozenfeld et al., 2010; Afefy, 2015; Bhatt, 2024; Nayanov & Khamidullina, 2022). These methods are applied to a broad hazard spectrum (physical, chemical, ergonomic, psychological) using qualitative tools (risk matrices) and sometimes quantitative models or Bayesian networks (Sharma & Tiwari, 2025; Pratama et al., 2025; Chafaa et al., 2025 & Guetarni et al., 2018). Integrating several techniques and safety software improves hazard identification and incident reduction (Sharma & Tiwari, 2025; Pratama et al., 2025; Rozenfeld et al., 2010; Afefy, 2015; Sani et al., 2024).

2.2 Job Safety Analysis

JSA is widely used in construction, process and manufacturing industries as a step-by-step task hazard identification and qualitative risk assessment tool (Sharma & Tiwari, 2025; Kusumastuti et al., 2024; Pratama et al., 2025; Ghasemi et al., 2023; Trisnayanti & Iriani, 2023). Strengths include worker involvement, detailed step-level hazards, and contribution to a proactive safety culture (Sharma & Tiwari, 2025; Kusumastuti et al., 2024; Pratama et al., 2025). Systematic reviews note key shortcomings: time-consuming execution, lack of standard hazard lists, no universal risk-ranking method, and, critically, limited consideration of hazards from surrounding or concurrent activities (Kwon et al., 2024; Pratama et al., 2025; Ghasemi et al., 2023). Recent advances link JSA with Bayesian networks, Petri nets, BIM and "dynamic" or "energy-based" JSA, but still focus mainly on job or sequence, not on plant-wide concurrency (Sharma & Tiwari, 2025; Kwon et al., 2024; Ghasemi et al., 2023).

2.3 Simultaneous Operations (SIMOPS) Management

SIMOPS in oil, gas and maritime contexts is defined as independent operations executed concurrently under common control, where each can affect the others' risk (Kwon et al., 2024; Arukhe et al., 2016; Pemberton et al., 2015; Fan et al., 2021; Ajimoko, 2016). Case studies and reviews describe compatibility assessments, auditable matrices and 4M (Measurement, Mitigation, Monitoring & Management) planning models, but these are largely qualitative and workshop driven, and require extensive data and personnel (Kwon et al., 2024; Arukhe et al., 2016; Pemberton et al., 2015; Fan et al., 2021; Ajimoko, 2016). LNG bunkering and deepwater drilling work highlight the need for spatio-temporal tools and near real-time updates, yet formal, rule-based SIMOPS risk models remain limited (Pemberton et al., 2015; Fan et al., 2021; Ajimoko, 2016).

Notably, one recent framework (HIRAS) explicitly standardizes JSA data (location, time, hazard attributes) and synchronizes them to detect hazard interactions between concurrent maintenance tasks, achieving high recall versus experts (Kwon et al., 2024). This directly addresses the classic JSA weakness on inter-job relationships, but is focused on maintenance SIMOPS rather than permit integration.

2.4 Permit to Work Systems and Their Digitalization

The PTW is a central procedural barrier for high-risk and non-routine work (hot work, confined spaces, electrical, etc.), but traditional systems show recurrent weaknesses: inadequate training, poor handover, paper-based limitations, weak leadership and auditing (Arukhe et al., 2016; Iliffe et al., 1999; Djunaidi & Umami, 2024). Early computerized PTW linked permits to incident databases to surface "unknown or forgotten" hazards during authorization (Iliffe et al., 1999). More recent electronic PTW (e-PTW) designs use mobile/cloud, GPS, biometrics, IoT locks and messaging integration to strengthen on-site verification and isolation and reduce human error, but still mainly digitize forms and workflows rather than perform automated inter-permit conflict detection or reasoning (Sharma & Tiwari, 2025; Arukhe et al., 2016; Djunaidi & Umami, 2024; Sani et al., 2024).

2.5 Research Gap

The review reveals a clear gap. JSA delivers task level risk estimates but does not address concurrency. SIMOPS workshops produce compatibility judgements but are slow, periodic, and not directly tied to permit issuance. PTW systems control authorization but lack a reasoning layer to combine the two preceding inputs. Nevertheless, there is still no widely reported, unified framework that integrates the three components into a single, auditable and real-time decision pipeline suitable for routine industrial use. The IPTW framework presented in Section 3 is designed to fill this gap.

3. Proposed IPTW Framework

3.1 IPTW Architecture

The proposed Intelligent Permit to Work (IPTW) framework is organized in five interacting layers, illustrated conceptually in Figure 1. The Knowledge-Base Layer (L1) stores structured records of work activities, hazards, controls, the SIMOPS compatibility matrix, and the spatial topology of the site. The Risk-Assessment Layer (L2) executes the JSA algorithm on each permit request, producing a pre-mitigation and post-mitigation risk index. The Concurrency Detection Layer (L3) queries the active-permit database and determines, for each permit pair, whether the activities overlap in time and space. The Decision Layer (L4) combines the JSA index and the SIMOPS compatibility values through a deterministic rule set and emits a four-state outcome. Finally, the Communication Layer (L5) notifies the relevant stakeholders, records the audit trail, and feeds incident or near-miss data back into the Knowledge Base for continuous learning.

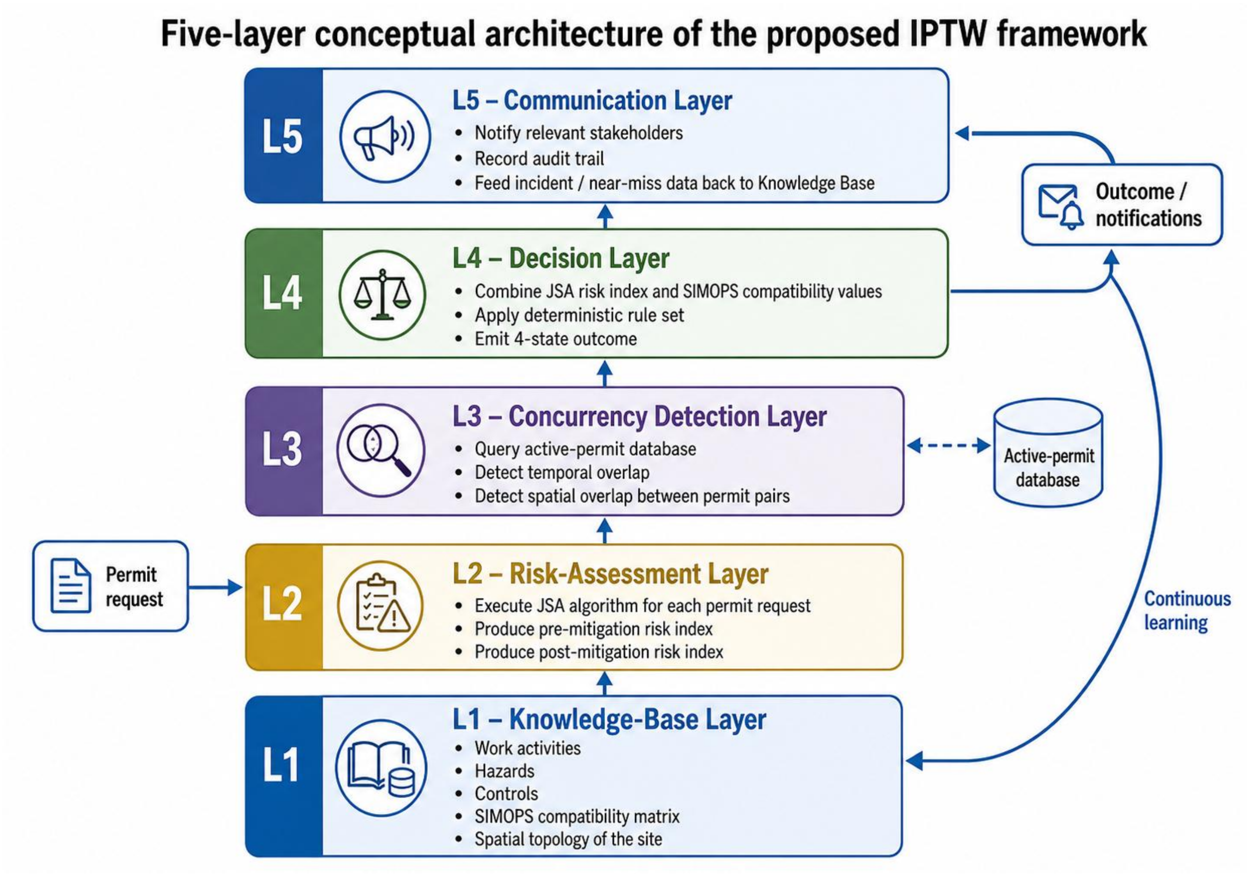

Figure 1. Five-layer conceptual architecture of the proposed IPTW framework.

3.2 Risk-Scoring Scheme

The framework adopts a 5×5 severity-probability matrix consistent with the practice in the Algerian process industry and aligned with IEC 31010:2019. Severity (G) is graded on a five-level ordinal scale (Table 1), and probability (P) is graded on a five-level alphabetical scale (Table 2).

Table 1. Severity scale (G)

Level	Label	Human consequence	Asset/Production	Environment
1	Negligible	First aid only, no lost time	Minor disruption, < 1 h	No off-site impact
2	Minor	Restricted work, no permanent injury	Local damage, < 1 day	Local, reversible effect
3	Moderate	Lost-time injury, full recovery	Equipment damage, < 1 week	Reportable spill, contained
4	Major	Serious injury, permanent disability	Unit shutdown, > 1 week	Major spill, off-site
5	Catastrophic	Single or multiple fatalities	Asset destruction, > 1 month	Long-term ecological damage

Table 2. Probability scale (P)

Level	Label	Qualitative meaning	Indicative annual frequency
1	Improbable	Not expected during plant lifetime	$< 10^{-4}$
2	Remote	Possible but unlikely during plant lifetime	$10^{-4} – 10^{-3}$
3	Occasional	Has occurred in similar facilities	$10^{-3} – 10^{-2}$
4	Probable	Expected to occur during plant lifetime	$10^{-2} – 10^{-1}$
5	Frequent	Expected to occur several times per year	$> 10^{-1}$

The Risk Number (NR) is defined by the product of the numerical severity and the numerical probability:

$$NR = G \times P, \quad NR \in [1, 25] \qquad (1)$$

Four risk classes are derived from NR thresholds, as summarized in Table 3.

Table 3. Risk-class thresholds

Risk Class	NR range	Acceptance criterion
Low	1 – 4	Acceptable as is; routine monitoring
Medium	5 – 9	Acceptable with documented controls (ALARP)
High	10 – 15	Acceptable only with additional measures
Critical	16 – 25	Not acceptable; work must not proceed

3.3 JSA Module Formulation

For a given work activity i, the JSA module evaluates two states: the inherent state (without controls) and the residual state (with current controls). Let G_pre,i and P_pre,i be the inherent severity and probability, and G_post,i and P_post,i their residual counterparts. The pre- and post-mitigation Risk Numbers are:

$$NR\_pre,i = G\_pre,i \times P\_pre,i \qquad (2)$$

$$NR\_post,i = G\_post,i \times P\_post,i \qquad (3)$$

To quantify the effectiveness of the implemented control measures, we introduce the Risk Reduction Efficiency (RRE):

$$RRE\_i = (NR\_pre,i - NR\_post,i) / NR\_pre,i \times 100\ \% \qquad (4)$$

RRE is dimensionless, bounded in [0, 100], and admits a direct managerial interpretation: a value of 80% indicates that the control measures eliminate four-fifths of the inherent risk associated with the activity. The framework adopts an acceptance threshold NR_post $\leq$ 6 (i.e., Low or low-Medium class), consistent with the As Low As Reasonably Practicable (ALARP) principle. Any activity whose residual risk exceeds this threshold must be redesigned or refused.

3.4 SIMOPS Compatibility Module

The SIMOPS module evaluates whether two activities i and j can be performed concurrently in the same or in adjacent zones. We define a compatibility function C(i, j) taking three discrete values:

Table 4. SIMOPS compatibility categories

C(i,j)	Category	Operational meaning	Permit consequence
0	Incompatible	The two activities introduce a non-mitigable interaction risk	DEFER until one activity is finished
1	Conditionally compatible	The two activities can coexist provided additional barriers are in place	CONDITIONAL GRANT (extra barriers)
2	Compatible	No significant interaction; standard barriers are sufficient	GRANT (standard conditions)

The compatibility values are populated through a structured SIMOPS workshop following the procedure described in (IOGP, 2016) and reviewed periodically. For each pair classified as conditionally compatible, the framework also stores the list of additional barriers that must be in place for instance, mandatory gas testing before hot work, or radiation-shielding curtains during simultaneous radiography.

3.5 IPTW Decision Algorithm

The decision engine combines the JSA module, the SIMOPS module, and the active permit registry into a deterministic algorithm that returns one of four outcomes: GRANT, CONDITIONAL GRANT, DEFER, or DENY. The pseudo-code is given in Algorithm 1.

Algorithm 1. i-PTW decision logic

```
INPUT:  P_new = (T_i, Z_k, [t1, t2])         // requested permit
        JSA_DB                                 // JSA records
        SIMOPS_M                               // compatibility matrix
        ACTIVE                                 // active permit registry


1.   Retrieve JSA(T_i) → (NR_pre,i, NR_post,i, controls_i)
2.   IF NR_post,i > 6 THEN  RETURN DENY ("Residual risk above tolerance")
3.   Conflicting ← {P_j ∈ ACTIVE : Z_k ∩ Z_j ≠ ∅ AND [t1,t2] ∩ [t1_j,t2_j] ≠ ∅}
4.   IF Conflicting = ∅ THEN  RETURN GRANT (controls_i)
5.   required_extra ← ∅
6.   FOR each P_j ∈ Conflicting DO
         c ← SIMOPS_M[T_i, T_j]
         IF c = 0 THEN  RETURN DEFER ("Incompatible with active task T_j")
         IF c = 1 THEN  required_extra ← required_extra ∪ Barriers(T_i, T_j)
     END FOR
7.   IF required_extra ≠ ∅ THEN  RETURN CONDITIONAL_GRANT(controls_i ∪ required_extra)
8.   RETURN GRANT (controls_i)
```

The algorithm is deterministic, runs in O(n) for n active permits, and produces a complete audit trail that includes the JSA reference, the SIMOPS reference, the list of conflicting permits, and the decision rationale. This auditability is critical for regulatory inspection and for incident investigation.

3.6 Implementation Architecture

The framework is intended to be implemented as a web application accessible from desktop and mobile devices used in the field. The Knowledge Base Layer can be realized through a relational database coupled with a geographical zone schema. The Risk Assessment and Decision Layers are stateless services that can be deployed in containers. The Communication Layer interfaces with email, SMS, and SCADA systems for real-time notification. Although the present paper does not develop a software prototype, the algorithmic specification of Section 3.5 is sufficient for direct implementation.

4. Case Study: Algerian Steel Complex

4.1 Site Description

Tosyali-Algeria is an integrated iron and steel complex located in the industrial zone of Bethioua, approximately 40 km east of Oran, Algeria. The plant covers an area of 4 km² and is connected to the Mediterranean coast by a 14 km mineral conveyor. It is one of the largest steelmaking facilities in North Africa, with a production capacity exceeding 2.5 million tons of liquid steel per year. The complex is structured around eight main process units: Direct Reduction (DRI), palletization, electric-arc furnace melting, continuous casting (CCM), rolling mills, an air separation unit, an electrical substation, and the auxiliary maintenance, storage, and quayside facilities. The site operates 24/7 under the supervision of an HSE department, and hosts a permanent workforce of several thousand employees and contractors.

4.3 Selected Work Activities

Table 5. Work activities selected for the case study

No.	Activity	Permit family	Typical zones at Tosyali
1	Lifting operations	Lifting permit	EAF bay, CCM bay, storage yards
2,3	Hot work (welding, cutting, grinding) and Hot work in ATEX Zone	Hot-work permit	Maintenance workshops, all production units
4	Industrial radiography (NDT)	Radiography permit	Spiral-tube QC area, weld inspection bays
5	Cold work (painting, light maintenance)	Cold-work permit	All units, structural steel surfaces
6	Pressure testing	Cold/hot-work permit	Finished-product QC, piping circuits
7	Work at height	Height-work permit	Scaffolding around furnaces, tanks, gantries

5. Results

5.1 JSA Outcomes for the Six Selected Activities

For each of the seven activities, the JSA worksheet identified the principal hazards, the worst credible consequences, and the existing engineering, organizational, and personal protective controls. The pre- and post-mitigation Risk Numbers were then computed using Equations (1) to (3), and the Risk Reduction

Efficiency was calculated using Equation (4). The consolidated results are reported in Table 6, and the principal hazards per activity are summarized in Table 7.

Table 6. JSA risk indices and Risk Reduction Efficiency for the seven selected activities at Tosyali-Algeria

Activity	G_pre	P_pre	NR_pre	Class	G_post	P_post	NR_post	Class	RRE (%)
Lifting	5	3	15	High	2	2	4	Low	73.3
Hot work ATEX	5	4	20	High	2	2	4	Low	80
Hot work	4	3	12	High	2	2	4	Low	66.7
Radiography	5	3	15	High	2	3	6	Medium	60.0
Cold work (painting)	3	3	9	Medium	2	1	2	Low	77.8
Pressure testing	4	3	12	High	2	1	2	Low	83.3
Work at height mobile scaffold	5	4	20	Critical	2	2	4	Low	80.0
Work at height fixed scaffold	5	4	20	Critical	3	1	3	Low	85.0
Work at height night	5	4	20	Critical	2	2	4	Low	80.0
Mean RRE									75.4

Three observations emerge from Table 6. First, all nine residual indices fall at or below the acceptance threshold NR_post ≤ 6, confirming that the existing portfolio of controls is sufficient to bring every activity into the ALARP region. Second, the average RRE of 75.4% indicates a high level of control effectiveness. Third, radiography is the activity with the lowest RRE (60.0%) an expected outcome given that ionizing radiation hazards cannot be eliminated and can only be limited through shielding, distance, and time exposure.

Table 7. Principal hazards identified per activity

Activity	Principal hazards
Lifting	Collision with installations; falling objects; equipment overload; rigging failure; adverse weather
Hot work	Fire and explosion; sparks ignition of flammables; burns; electrocution; eye and respiratory injury
Radiography	Ionizing-radiation exposure; radiological injury; chronic occupational disease
Cold work (painting)	Toxic VOC exposure; fire from flammable solvents; environmental contamination; electrocution near energized parts
Pressure testing	Stored-energy release; uncontrolled depressurization; projectile damage; injury to bystanders
Work at height	Fall from height; falling objects; scaffold collapse; weather exposure; communication failure (night)

5.2 Risk-Reduction Effectiveness

Figure 2 presents the pre- and post-mitigation Risk Numbers for the seven core activities (work at height aggregated to the worst sub case). The visualization makes apparent the steep risk reduction achieved on lifting, hot work, work at height, and pressure testing, and contrasts it with the more modest reduction obtained on radiography. This pattern provides direct managerial guidance: control investment for radiography should focus on procedural and time-exposure controls rather than on additional engineering barriers, since the inherent severity cannot be reduced.

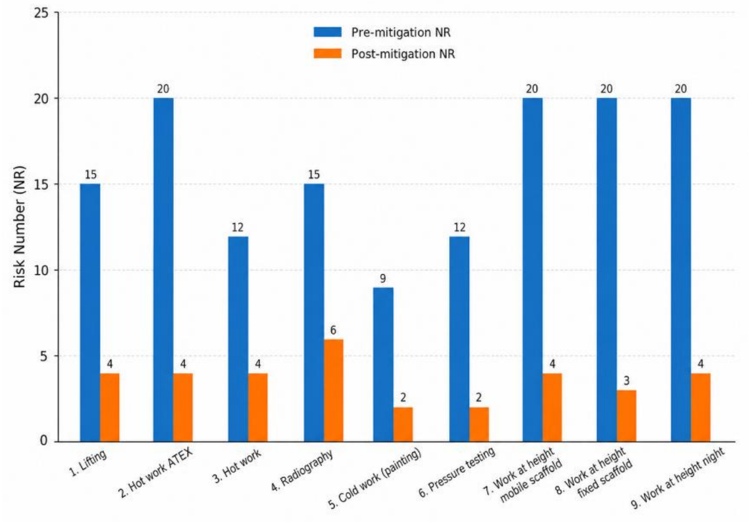

Figure 2. Pre- vs. post-mitigation Risk Numbers for the activities at Tosyali-Algeria.

5.3 SIMOPS Compatibility Analysis

Three SIMOPS scenarios were selected for full evaluation, based on their reported frequency at the Tosyali site during the observation period. For each scenario, the workshop method described in Section 3.4 was followed: the pair of activities was characterized, the interaction hazards were enumerated, the worst credible consequences were graded against the four-axis matrix (People, Assets, Environment, Reputation), and the compatibility category was assigned. The results are summarized in Table 8.

Table 8. SIMOPS compatibility evaluation of three scenarios at Tosyali-Algeria

Scenario	Activity i × Activity j	Dominant interaction hazard	Worst-credible NR	C(i,j)	Outcome
S1	Hot work (Zone 2) × Radiography	Fire/explosion ignited by hot-work sparks in vicinity of radioactive source; bystander irradiation	5C = 15 (High)	0	Incompatible
S2	Hot work (Zone 1) × Cold work (painting)	Ignition of solvent vapours by hot-work sparks; toxic-fume accumulation	3B = 6 (Medium)	1	Conditionally compatible
S3	Cold work × Lifting operations	Personnel struck by load; container spill from poor positioning of lifting equipment	2B = 4 (Low)	2	Compatible

Scenario S1 confirms the operational rule that hot work and radiography must be strictly sequenced: the combination is judged incompatible because it stacks two independent high-severity hazards (fire ignition and ionizing radiation) whose joint probability cannot be reduced to ALARP. Scenario S2 is conditionally compatible: it is permissible only after gas-free verification, removal of flammable inventories, dedicated fire watch, and ventilation. Scenario S3 is fully compatible under standard PTW conditions.

5.4 IPTW Decision Outcomes

Algorithm 1 was applied to a set of synthetic permit-request streams reproducing the three SIMOPS scenarios above. Table 9 reports the input conditions and the outcome returned by the decision engine.

Table 9. i-PTW decision outcomes for the three SIMOPS scenarios

Scenario	Active permit (T_j)	New request (T_i)	NR_post,i	C(i,j)	Decision
S1	Radiography in Zone 2	Hot work in Zone 2	4 (Low)	0	DEFER (until radiography completed)
S2	Painting in Zone 1	Welding in Zone 1	4 (Low)	1	CONDITIONAL GRANT (gas test, fire watch, ventilation, hot-work isolation)
S3	Painting in Zone 4	Lifting in Zone 4	4 (Low)	2	GRANT (standard barriers)

The three outcomes correctly reproduce the decisions that an experienced HSE supervisor would reach manually, with two important added benefits: the decisions are produced instantaneously and consistently, removing the variability associated with human judgement under time pressure; and every decision is accompanied by a structured rationale that is immediately available for audit, training, and incident investigation.

6. Discussion

6.1 Effectiveness of the Integrated Approach

The case study results support three claims about the proposed framework. First, the introduction of the Risk Reduction Efficiency indicator transforms the JSA worksheet from a purely qualitative document into a quantitatively interpretable record. Managers can use RRE to compare control investments across activities, to set internal performance targets, and to monitor drift over time. Second, the formalization of the SIMOPS compatibility function as a three valued discrete variable removes the ambiguity that often surrounds the color-coded matrices currently in use; the same input now always returns the same output. Third, the integration of the two modules into a single rule-based decision algorithm closes the loop between hazard analysis and operational authorization, which has historically been the weakest link of the PTW chain.

6.2 Operational Implications for the Steel Industry

Steel-making facilities such as Tosyali-Algeria are characterized by continuous operation, multi-contractor maintenance windows, and high-energy hazards (molten metal, electric arcs, pressurized systems). In this environment, the manual coordination of permits is particularly fragile, and the financial cost of an inappropriate concurrent-work decision can reach several million euros in lost production and asset damage. The proposed IPTW framework offers an immediately deployable governance layer that is compatible with existing JSA worksheets and SIMOPS workshops. No replacement of legacy procedures is required; only a structured digital interface and a small set of decision rules need to be added.

6.3 Comparison with Conventional Permit to Work

Conventional PTW practice relies on the issuing authority to mentally verify the residual risk of the requested task and its compatibility with all currently active permits in the area. As the number of concurrent permits grows, the mental load grows non-linearly, and omissions become inevitable. The IPTW framework offloads both verifications to a deterministic algorithm whose output is reproducible and auditable. The algorithm does not replace the issuing authority it provides a recommendation that the authority can accept, override (with documented justification), or escalate. This human in the loop design preserves accountability while reducing cognitive burden.

6.4 Limitations and Future Work

Three limitations of the present work should be acknowledged. First, the framework assumes that the SIMOPS compatibility matrix has been correctly populated; an erroneous classification will propagate to the decision output. The matrix should therefore be subject to periodic peer review and to update following incidents and near-misses. Second, the spatial overlap test in Algorithm 1 is implemented at the granularity of pre-defined work zones; finer granularity (e.g., 3D bounding boxes from BIM models) would improve detection in congested areas. Third, the case study is limited to a single site and to three SIMOPS scenarios; a multi-site validation across different industrial sectors would strengthen the external validity of the results.

Future work will focus on three extensions: the integration of a machine-learning module trained on historical permit and incident data to flag SIMOPS pairs whose compatibility classification appears to drift over time; the coupling of the IPTW decision engine with real-time gas-detection and personnel-tracking sensors, enabling dynamic re-evaluation of active permits; and a cross-sector validation campaign covering at least one oil and gas, one petrochemical, and one power generation site.

7. Conclusion

This paper has presented an integrated decision-support framework that unifies Job Safety Analysis, Simultaneous Operations compatibility evaluation, and a rule-based decision engine into a coherent Intelligent Permit to Work (IPTW) architecture. The framework is grounded in a 5×5 severity-probability matrix, introduces a Risk Reduction Efficiency indicator to quantify control effectiveness, formalizes SIMOPS compatibility as a three-valued discrete function, and translates these inputs into a four-state permit decision through a deterministic algorithm.

Validation on the Tosyali-Algeria integrated steel complex demonstrated three outcomes. First, the existing portfolio of controls at the site achieves an average Risk Reduction Efficiency of 75.4% across seven representative activities, with all residual risks falling within the ALARP region. Second, the SIMOPS compatibility analysis correctly classified the three scenarios under study as Incompatible (hot work × radiography), Conditionally Compatible (hot work × cold work), and Compatible (cold work × lifting). Third, the IPTW decision algorithm reproduced the decisions of an experienced HSE supervisor in all tested scenarios, with the additional benefits of instantaneous response, perfect reproducibility, and full auditability.

The framework is immediately deployable in heavy industry environments and requires no replacement of existing JSA or SIMOPS practices. Future work will extend the architecture with machine learning components, real-time sensor integration, and a multi-site cross-sector validation.

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