Open Journal of Safety Science and Technology, 2025, 15(3), 257-281
https://www.scirp.org/journal/ojsst
ISSN Online: 2162-6006
ISSN Print: 2162-5999

Maximizing Environmental, Health and Safety (EHS) Benefits in Process Industries through Implementation of e-PTW System - Ruwais Petrochemical Plant Case Study

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How to cite this paper: Ekanem, U.I. (2025) Maximizing Environmental, Health and Safety (EHS) Benefits in Process Industries through Implementation of e-PTW System - Ruwais Petrochemical Plant Case Study. *Open Journal of Safety Science and Technology*, **15**, 257-281.
https://doi.org/10.4236/ojsst.2025.153014

Received: June 4, 2025
Accepted: September 16, 2025
Published: September 19, 2025

Abstract

The historical context of major industrial disasters provides compelling evidence for the significance of digitizing the permit-to-work systems and control of work processes. Catastrophic events such as the BP Texas City Refinery explosion (2005) and the Piper Alpha disaster (1988) share common root causes directly related to permit-to-work failures. The Ruwais Petrochemical Plant, an ADNOC Group company and a significant player in the world petrochemical, oil, and gas market at some time, was grappling with the limitations of a traditional work control and permit-to-work (PTW) system, a safety and operational risk that drove the organization to transform its work control process. This study was designed to investigate how organizations can maximize Environmental, Health and Safety (EHS) benefits through the implementation of electronic PTW (e-PTW) systems in petrochemical operations. The research employed a single-case study methodology examining the Ruwais Petrochemical Plant implementation experience. A comprehensive audit of the existing paper-based system was conducted to identify systematic deficiencies, followed by gap analysis and market evaluation of available e-PTW solutions. Critical analysis of system functionalities was performed against identified requirements, leading to the selection and implementation of an appropriate digital solution. Process mapping techniques were employed to develop "as-is" and "to-be" workflows, whilst economic analysis examined implementation costs and operational benefits over a 12-month period. The results demonstrated successful resolution of 15 major systematic deficiencies in the paper-based system. Economic analysis revealed total implementation costs of $340,000 offset by annual operational benefits of $210,667, achieving investment recovery by month 19. Through detailed analysis of implementation methodology, operational improvements, and comprehensive economic evaluation, this research offers evidence-based insights for organizations contemplating comparable digital transitions. The results of this research demonstrate that a systematic approach to PTW digitization can address fundamental safety management challenges whilst delivering substantial operational and economic benefits for process industry organizations.

Keywords

Electronic Permit-to-Work, Process Safety, Risk Management in Petrochemical Industry, Safety Management Systems, Work Control System, Digital PTW System Benefits

1. Introduction

The petroleum industry handles large quantities of flammable and toxic materials, creating a serious potential for accidents [1] [2]. According to Ghosh (2021), process industries face increasing safety challenges because of increasing operational complexity and regulatory demands [3]. To prevent incidents, it is vital that safe systems of work are established and maintained throughout operational activities [4]. In line with this, incidents in process facilities occur because of several factors ranging from failures in implementing correct procedures to a lack of training, instruction, or understanding of Permit to Work (PTW) systems [5] [6]. A study by Okoh (2015) reviewing major accidents in the U.S. and Europe found that 44% of 183 major accidents were linked to maintenance, and that 30% - 40% of all accidents in the chemical process industry are maintenance-related [7]. The PTW system is widely used across Oil, Petrochemical, Energy and Chemical industries as a fundamental safety management tool [4] [8]. This goes to show what the permit-to-work form represents a written and signed statement resulting from work safety procedures, ensuring the establishment of safe conditions for work commencement and maintenance of safety throughout task duration, including emergency arrangements [9]. De Freitas *et al.* (2023) emphasize that PTW systems provide agreed safe systems of work that prevent instruction omission and misinterpretation during hazardous activities [6].

Historically, PTW systems have been paper-based until organisations became more focused on effectively managing hazards associated with work control [1]. According to De Lima-Omorog *et al.* (2018) and Gichuru (2023), this transformation has driven widespread digitization of permit systems, and digital PTW represents an end-to-end solution synchronizing operational, maintenance, scheduled and unscheduled activities within organisations [10] [11]. These systems function as accurate compliance tools distributed through digital means to increase operational efficiency and productivity while addressing maintenance and work management domains [12]. Like paper-based predecessors, effective electronic PTW (e-PTW) systems are risk-based, adopting risk assessment as the fundamental driver for safety decisions [9]. However, De Freitas *et al.* (2023) explained that digitization offers substantial opportunities to enhance safety performance beyond traditional approaches through improved data management, real-time monitoring, and systematic risk control [6].

This paper presents a comprehensive case study analysis of e-PTW system implementation in petrochemical operations, specifically examining the Ruwais Petrochemical Plant experience. The research employs a systematic methodology combining comprehensive auditing of existing paper-based systems, gap analysis, market evaluation, and implementation assessment to understand how organisations can maximize Environmental, Health and Safety (EHS) benefits through PTW digitization. The study also addresses critical research questions regarding the practical implementation challenges of e-PTW systems, the systematic benefits achievable through digitization, and the economic justification for such investments in process industries. Through detailed analysis of implementation methodology, operational improvements, and comprehensive economic evaluation, this research provides evidence-based insights for organisations considering similar digital transformations. The paper contributes to existing literature by providing a structured framework for e-PTW implementation based on real operational experience, quantifying tangible and intangible benefits achieved through systematic digitization, and offering detailed economic analysis supporting investment decisions in process safety technology. The findings demonstrate how systematic approach to PTW digitization can address fundamental safety management challenges whilst delivering substantial operational and economic benefits.

2. Research Methodology

This section outlines the systematic approach employed to investigate the implementation and benefits of electronic Permit-to-Work (e-PTW) systems in petrochemical facilities, using the Ruwais Petrochemical Plant as a primary case study.

2.1. Research Design

This study employs a single-case study methodology, which Yin (2018) argues is appropriate when examining contemporary phenomena within real-life contexts where boundaries between phenomenon and context are not clearly evident [13]. According to Carter (2020) and Hancock *et al.* (2021), case study research provides in-depth understanding of complex organizational processes and their outcomes [14] [15]. The selection of a single-case design was justified given the unique nature of large-scale e-PTW implementation in petrochemical facilities, where comprehensive access to operational data and processes is typically restricted [3] [16]. The research adopts a mixed-methods approach, combining qualitative process analysis with quantitative performance metrics. According to Creswell and Clark (2017), this triangulation strategy enhances validity by providing multiple perspectives on the same phenomenon [17]. The methodology follows established frameworks for technology implementation studies in high-risk industries [2] [11]. The established frameworks referenced are the Center for Chemical Process Safety (CCPS) Process Safety Management (PSM) Framework for systematic safety system evaluation shown in **Figure 1** below, and Yin's Case Study Research Framework for contemporary phenomenon investigation in real-life contexts shown in **Figure 2** below, both of which directly support the audit-based gap analysis and process mapping methodology used in this study [14] [18].

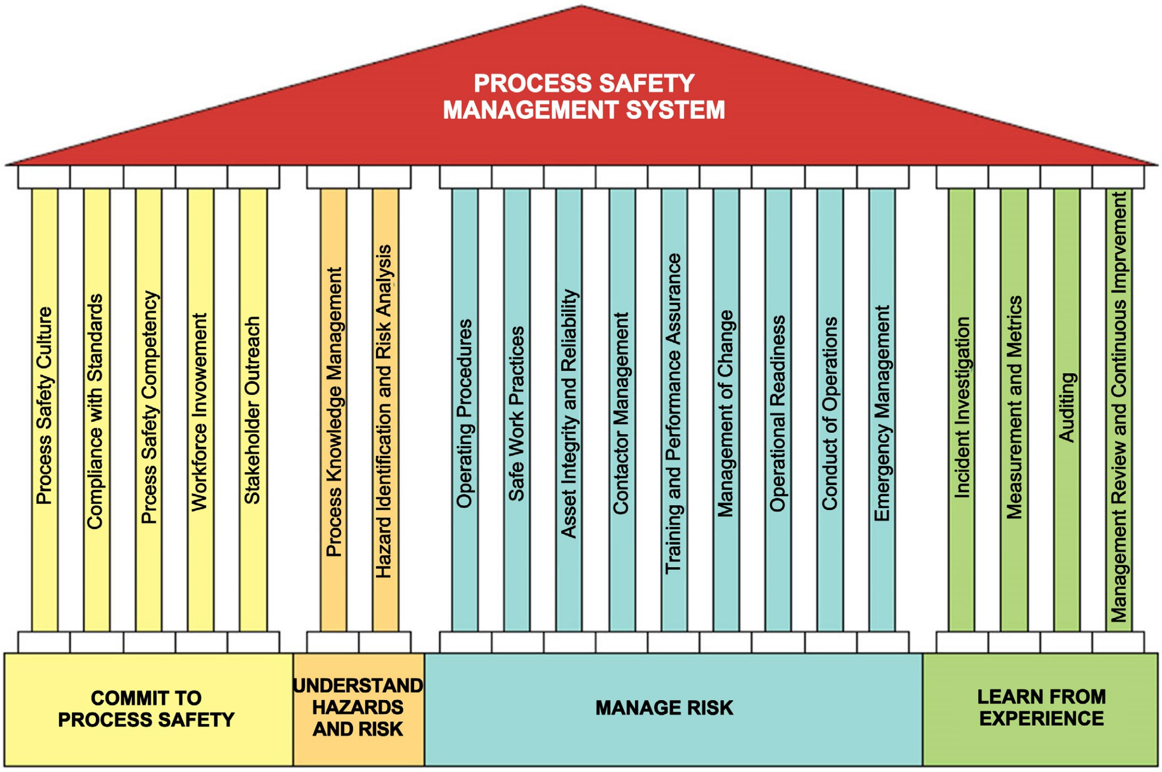

Figure 1. The CCPS process safety management. **Source:** Kadri (2021) [18].

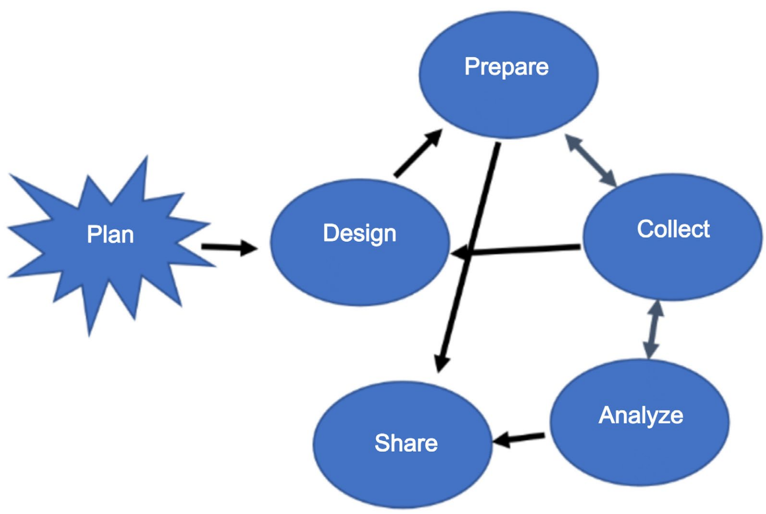

Figure 2. Yin's case study research framework. **Source:** Adapted from Yin (2018) [13].

2.2. Case Selection and Context

The Ruwais Petrochemical Plant was selected as the case study site based on several criteria identified by Rule and John (2015) for effective case selection, which are novelty, theoretical relevance, potential for replication, and the opportunity to observe the phenomenon in a real-life context [19]. The facility represents a typical large-scale petrochemical operation where PTW systems are critical for operational safety. This is because it mirrors common industry practices and operational conditions found in other major refineries and also because high-risk activities in such plants require strict control over work permissions to prevent accidents [2]. According to Mah (2023), facilities of this scale and complexity provide representative contexts for understanding industry-wide challenges and solutions, because their challenges and systems reflect those faced across the broader petrochemical sector [20]. The plant's transition from paper-based to electronic PTW systems occurred over a defined implementation period, providing clear temporal boundaries for analysis. This temporal aspect is very important for case study research, as noted by Welch *et al.* (2019), helping in the before-and-after comparisons, which are necessary for evaluating how effective the implementation process is [21].

2.3. Data Collection Methods

2.3.1. Comprehensive System Audit

The primary data collection method involved a comprehensive audit of the existing paper-based PTW system. This audit methodology follows established frameworks for process safety management evaluation, which encompass systematic examination of permit procedures, documentation practices, and operational workflows across all process units [22]. According to Nugroho *et al.* (2024), comprehensive audits in process industries should examine both procedural compliance and practical implementation gaps [23]. The audit process involved detailed documentation of current practices, identification of procedural deviations, and assessment of system effectiveness against industry best practices.

2.3.2. Gap Analysis Framework

Following the audit, a structured gap analysis was conducted using established frameworks recommended by the Center for Chemical Process Safety and aligned with ISO 45001 (**Figure 3**), and IEC 61511 (**Figure 4**) standards for process safety system evaluation [24] [25] [26]. Example of these frameworks is the CCPS Risk-Based Process Safety (RBPS) framework (**Figure 1**), in which the Center for Chemical Process Safety emphasises that it is very helpful in the systematic identification of deficiencies in safety management systems [25].

The gap analysis employed a matrix-based approach, comparing current practices against industry standards including IEC 61511 (Functional Safety of Safety Instrumented Systems) and ISO 45001 (Occupational Health and Safety Management Systems) [26] [28].

Figure 3. Key components of the ISO 45001 standards for process safety system evaluation. **Source:** Xenia Team (2024) [27].

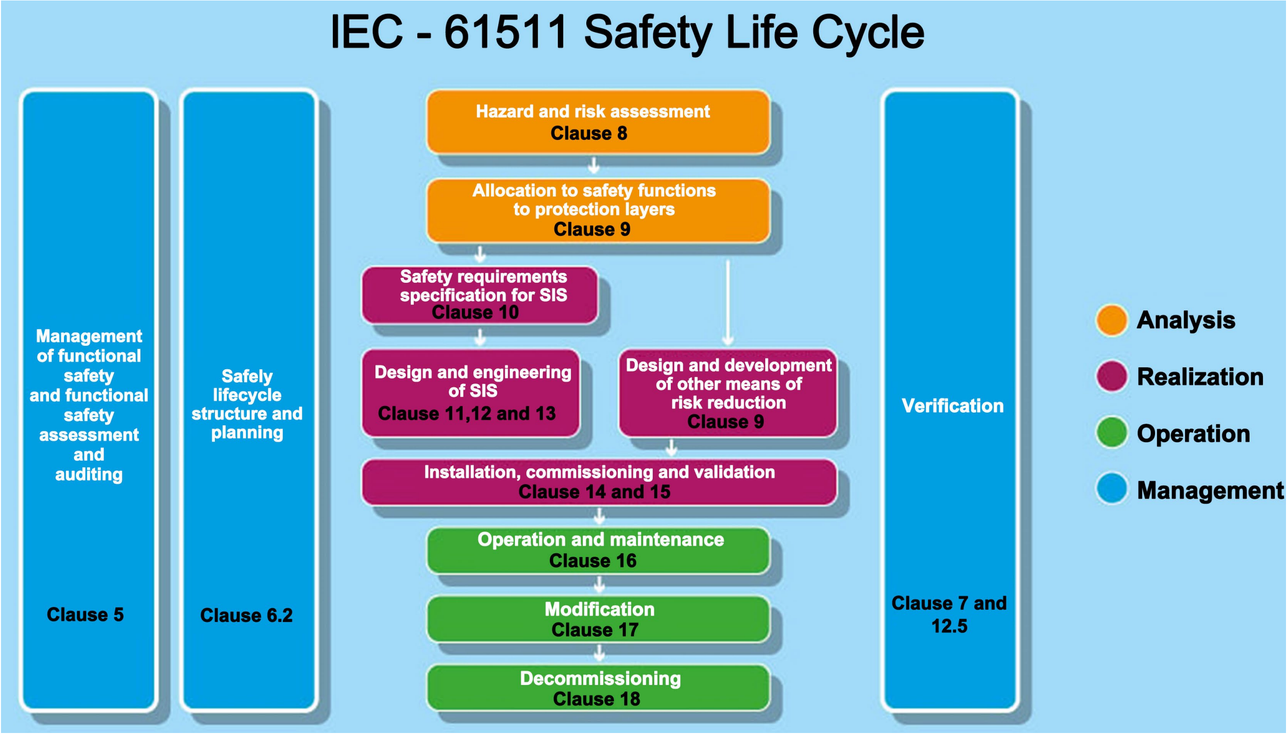

Figure 4. The IEC 61511 standards for process safety system evaluation. **Source:** GM International (2021) [29].

This comparison method is supported by Donaldson *et al.* (2015), who explained that it is effective in identifying critical improvement areas in industrial safety systems [30].

2.3.3. Market Research and Technology Evaluation

A systematic market research process was undertaken to evaluate available e-PTW solutions. This process followed established frameworks for technology selection in process industries, which involved critical analysis of system functionalities against identified requirements, with particular focus on addressing deficiencies revealed through the gap analysis [31] [32]. As highlighted by Jamwal *et al.* (2021) and Kozłowska (2022), the selection criteria development process aligns with multi-criteria decision analysis (MCDA) methodologies recommended for complex technology investments [33] [34]. Each potential solution was evaluated against defined criteria including functionality coverage, system integration capabilities, and alignment with operational requirements.

2.4. Analytical Framework

2.4.1. Process Mapping Methodology

The study employed process mapping techniques to develop comprehensive "as-is" and "to-be" process models. According to process improvement literature by Simsekler *et al.* (2018) and Tong and Lv (2024), this approach provides clear visualisation of current state limitations and future state benefits [35] [36]. The mapping process followed established business process modelling notation (BPMN) standards like the BPMN 2.0 by the Object Management Group and the ISO/IEC 19510:2013 to ensure systematic documentation [28] [37]. Process mapping sessions involved key stakeholders including operations supervisors, maintenance coordinators, and safety personnel. This participatory approach aligns with stakeholder engagement principles outlined by Fauzi Rahman Jayaraman *et al.* (2020), ensuring a comprehensive understanding of operational realities and implementation challenges [38].

2.4.2. Cost-Benefit Analysis Framework

A structured cost-benefit analysis was conducted using established methodologies for technology investment evaluation in process industries. The established methodologies refer to Net Present Value (NPV) analysis and Return on Investment (ROI) calculations as recommended by the American Institute of Chemical Engineers (AIChE, 2022) for evaluating process safety technology investments, which directly supports the $650 weekly savings calculation presented in the Ruwais case study [39]. The analysis framework incorporated both direct and indirect costs, following guidelines established by the American Institute of Chemical Engineers (AIChE, 2022) [39]. The economic evaluation employed net present value (NPV) analysis over a defined time horizon, incorporating factors including implementation costs, operational savings, and risk mitigation benefits. This approach is supported by financial analysis literature for industrial technology investments [40].

2.5. Data Validation and Quality Assurance

Data validation employed triangulation methods recommended for case study research [14]. These triangulation methods refer to cross-referencing three data sources which are the comprehensive audit findings, the gap analysis results, and the market research evaluation to validate consistency across all findings before selecting the e-PTW solution. Multiple data sources were cross-referenced to ensure consistency and accuracy of findings, while operational data was validated through comparison with historical records and industry benchmarks to ensure the accuracy of the before-and-after implementation metrics, particularly the cost savings and process efficiency improvements identified in the audit.

Quality assurance processes included peer review of analysis methods and findings validation through stakeholder feedback sessions to verify that the gap analysis findings and solution selection criteria accurately reflected the actual operational challenges experienced at the Ruwais facility. This approach aligns with quality standards for case study research as recommended by Yin (2018) and Hancock *et al.* (2021), as they stated that case studies require multiple data sources and validation methods to ensure reliability and credibility of single-case study findings [13] [15].

2.6. Ethical Considerations

The research adhered to established ethical guidelines by the American Psychological Association (2017) for research in order to protect proprietary operational data and ensure participant anonymity during the comprehensive audit and gap analysis processes [41]. Confidentiality protocols were maintained for sensitive operational data, while ensuring sufficient detail for academic rigour by providing aggregated performance metrics and process descriptions without revealing specific equipment identifiers or proprietary system configurations. Informed consent was obtained from participants like operations supervisors, maintenance coordinators, and safety personnel, who participated in process mapping sessions and provided operational data for the audit, ensuring voluntary participation and transparency about research purposes.

2.7. Limitations

Several limitations were identified in the methodology. Based on the findings of Marková *et al.* (2020) and Kazdin (2021), the single-case design limits generalisability to other facilities, though this is offset by the detailed understanding gained. Also, access to certain proprietary information was restricted, requiring reliance on aggregated data for some analyses [42] [43]. Furthermore, the timeframe of the study limited long-term impact assessment, as the focus was mainly on immediate implementation outcomes.

The research methodology employed in this case study focused specifically on operational efficiency and Environmental, Health and Safety (EHS) performance benefits of e-PTW implementation. Cybersecurity assessment was outside the defined scope of this research framework, which concentrated on process safety improvements and economic benefits. While the implementation included standard IT security measures, which is shown in the economic analysis ($25,000 allocated for network security enhancements in Section 3.3.2.2), a comprehensive cybersecurity evaluation was not part of the systematic audit and gap analysis methodology employed. Such assessment would require dedicated cybersecurity research methodology and specialised data collection procedures beyond the current study's scope. The author acknowledge that cybersecurity considerations represent an important area for future research in industrial digitalisation projects and recommend this as a complementary study to the operational benefits analysis presented.

3. Findings - The Petrochemical Case

This section presents the detailed case study analysis of e-PTW implementation at the Ruwais Petrochemical Plant, applying the methodology outlined in Section 2.

3.1. Problem Areas before Implementation of Electronic Permit to Work System

Prior to the adoption of electronic based permit to work system, the petrochemical facility faced a series of systemic issues from the paper-based permit to work procedure, which could best be resolved by implementation of electronic based system. Prominent issues that led to the decision to implement the electronic permit to work system included:

- Frontline workers were noticed using construction P&IDs instead of as-built P&IDs as location references for the execution work approved.
- Existing company procedure requires contractor supervisors to be trained as PTW receivers, but some contractors used technicians for this role. That means the role of PTW receivers was degraded from supervisor level to technician level which created room for error and potential for incident due to poor supervision.
- Existence of many unplanned permits from project contractors leading to chaotic permit to work management in the Central Control Room (CCB).
- In some instances, permit receivers signed the permits even before the approver approves the permit.
- Simultaneous operations (SIMOPS) in some instances have not been correlated leading to exposure of personnel to hazards/risk.
- Most permits utilized for execution of work did not have complete documentation such as Task Risk Assessment (TRA), entry log sheet, rescue plan, and method statement.
- Level 2 isolations do not include electrical isolations. This became necessary because not all electrical equipment has racking arrangement due to the equipment design.
- Limitation in space (only 3 lines) that can be printed for description of the activity in System Applications and Products (SAP) System used in documenting the equipment master data.
- Closed permits were not always collected and archived by the planning department and EHS department.

- Many permits utilized for execution of work were not duly completed as general sections were mostly not filled completely by the respective owners. These sections were meant to be completed by respective asset owners or work execution team, and must be cross checked by operations supervisor prior to approving the permit.
- Most of the times, isolation completion certificates were not duly completed. The requirement is to have all sections of isolation completion certificates completed in accordance to procedure and cross referenced in the execution permit/permits.
- Permits being signed by permit receivers whose card has expired.
- Isolation completion certificates in many instances have not been cross referenced in the permits. Electrical isolations not logged on the permit as required by the procedure.
- Frontline personnel working in satellite instrument shelter and power substation without endorsement of permit by relevant instrument / electrical supervisor as required by the procedure.
- In some instances, closing of work permits by the receivers is being done by proxy instead of the responsible person closing the permit as required by the procedure.

3.2. Training Program Implementation

This section details the comprehensive training program implemented during the e-PTW system rollout, addressing the critical need for workforce competency development identified through the gap analysis methodology outlined in Section 2.

3.2.1. Training Program Framework

The training program followed established frameworks for industrial software implementation recommended by AIChE (2022) [39]. According to Bakar (2017), successful e-PTW implementations require systematic competency development across multiple stakeholder groups to ensure effective adoption and sustained operational benefits [4]. The program design incorporated adult learning principles and competency-based training methodologies. Ghosh (2021) emphasize that industrial training programs must address both technical system operation and underlying safety management principles to achieve lasting behavioural change [3]. The training framework addressed identified deficiencies from the paper-based system audit, ensuring systematic capability development.

3.2.2. Training Needs Analysis

Prior to program design, a comprehensive training needs analysis was conducted based on the system audit findings. The analysis identified specific competency gaps across different user groups, aligning with the 15 deficiencies documented in Section 3.1. According to De Lima-Omorog *et al.* (2018), training needs analysis for permit systems must address both procedural knowledge and practical application skills [10]. The analysis revealed varying training requirements across stakeholder groups. Operations supervisors required comprehensive system administration training, whilst frontline workers needed focused operational competencies. Contractor personnel presented additional challenges due to varying baseline competency levels and temporary engagement periods.

3.2.3. Training Program Structure

1) Multi-Tiered Training Approach

The training program employed a multi-tiered approach addressing different user categories and competency requirements. According to Chevalier (2020) tiered training approaches enable customized content delivery whilst maintaining consistent core competencies across all participants [44].

Tier 1: System Administrators and Operations Supervisors This tier addressed personnel responsible for permit approval and system administration. The training duration was 40 hours per participant, and it covered theoretical and practical components. The program covered system configuration, approval workflows, isolation management integration, and dashboard utilization for operational oversight.

Tier 2: Permit Receivers and Maintenance Coordinators This tier focused on personnel responsible for permit execution and field operations. The training duration was 24 hours per participant, emphasizing practical system operation, risk assessment integration, and field verification procedures. Special attention was given to addressing identified deficiencies related to permit receiver competency.

Tier 3: General Users and Contractor Personnel This tier addressed broader workforce requirements for system interaction and compliance. The training duration was 16 hours per participant, covering basic system navigation, permit status checking, and compliance requirements. Contractor-specific modules addressed role definition and supervisory requirements identified in the audit.

2) Training Content Development

Training content development followed systematic instructional design principles recommended for industrial applications [39]. Content addressed both technical system operation and underlying safety management concepts to ensure comprehensive understanding.

Core Training Modules:

- System navigation and user interface operation
- Risk assessment integration and Task Risk Assessment (TRA) development
- Isolation management and energy control procedures
- Simultaneous operations (SIMOPS) identification and management
- Permit approval workflows and authorization procedures
- Emergency response and permit suspension procedures
- Documentation requirements and audit trail maintenance.

Practical Application Components:

- Simulated permit processing exercises using actual facility scenarios
- System integration with existing SAP work order processes
- Dashboard utilization for real-time permit monitoring

- Troubleshooting and error resolution procedures

3.2.4. Training Delivery Methods

1) Blended Learning Approach

The program employed a blended learning approach combining classroom instruction, hands-on practice, and online resources. According to Nugroho *et al.* (2024), blended approaches maximize learning effectiveness whilst minimising operational disruption during periods [38]. These approaches are given below:

- **Classroom Instruction (60% of program duration):** Instructor-led sessions addressed theoretical concepts, system functionality, and procedural requirements. Sessions incorporated interactive discussions addressing specific facility challenges identified through the audit process. Group exercises facilitated knowledge sharing between experienced personnel and new system users.
- **Hands-On Practice (30% of program duration):** Practical sessions utilized a dedicated training environment replicating the production system configuration. Participants processed simulated permits showing actual facility scenarios, building competency through realistic application. Practice sessions addressed common error scenarios identified in the paper-based system audit.
- **Online Resources and Assessment (10% of program duration):** Supplementary online modules provided reference materials and competency assessment tools. Self-paced learning components enabled flexible scheduling around operational requirements. Online assessments verified competency achievement prior to system access authorization.

2) Competency Assessment Framework

Competency assessment employed multiple evaluation methods to ensure comprehensive capability verification. The framework aligned with industrial training standards recommended by AIChE (2022) [39]. The evaluation methods included the following.

- **Written Assessments:** Theoretical knowledge evaluation covering system functionality, procedural requirements, and safety management principles. Assessment criteria addressed specific deficiencies identified in the audit, ensuring systematic capability development.
- **Practical Demonstrations:** Hands-on system operation under instructor supervision, demonstrating competency in permit processing, approval workflows, and emergency procedures. Practical assessments utilized actual facility scenarios to ensure relevant skill development.
- **Ongoing Competency Monitoring:** Post-implementation competency monitoring through system audit trails and periodic refresher assessments. This approach addresses the identified deficiency of inadequate ongoing competency maintenance in the paper-based system.

3.2.5. Implementation Timeline and Participation

1) Phased Training Rollout

Training implementation followed a phased approach aligned with system deployment across process units. According to Kozłowska (2022), phased training rollouts enable systematic capability building whilst maintaining operational continuity [34]. The phases are as follows:

- **Phase 1 (Months 1 - 2):** Core Personnel Training Initial training focused on system administrators, operations supervisors, and key maintenance coordinators. This approach established competent change champions to support broader workforce development. A total of 45 core personnel completed comprehensive training during this phase.
- **Phase 2 (Months 3 - 4):** Operational Personnel Training Expanded training addressed permit receivers, maintenance technicians, and operations personnel across all process units. Training delivery utilized established core personnel as assistant instructors, building internal capability for ongoing support. A total of 120 operational personnel completed training during this phase.
- **Phase 3 (Months 5 - 6):** Contractor and Support Personnel Training Final phase addressed contractor personnel and support functions including planning, scheduling, and administrative staff. Special attention was given to contractor supervisor competency requirements identified as a critical deficiency in the audit. A total of 85 contractor and support personnel completed training during this phase.

2) Training Participation Statistics

Total training program participation encompassed 250 personnel across all categories. According to the training records analysis, participation rates achieved 98% completion across all required personnel, demonstrating strong engagement and management support for the implementation.

Training Hours Delivered:

- **Core personnel:** 1800 training hours (45 participants × 40 hours).
- **Operational personnel:** 2880 training hours (120 participants × 24 hours).
- **Contractor/support personnel:** 1360 training hours (85 participants × 16 hours).
- **Total training hours:** 6040 hours.

3.2.6. Training Effectiveness Evaluation

1) Competency Achievement Metrics

Training effectiveness evaluation employed multiple metrics aligned with industrial training assessment standards. According to Wang and Wang (2024), comprehensive evaluation requires both immediate competency verification and longer-term performance assessment [22].

Initial Competency Assessment Results:

- **Written assessment pass rate:** 96% (first attempt)
- **Practical demonstration pass rate:** 94% (first attempt)
- **Overall program completion rate:** 98%

These results demonstrate effective training design and delivery, significantly exceeding industry benchmarks for complex industrial software training programs.

2) Post-Implementation Performance Impact

Training effectiveness validation through post-implementation performance monitoring revealed substantial improvements in permit processing quality. Analysis of permit data for the six months following training completion showed significant reduction in the deficiencies identified in the original audit.

Performance Improvement Metrics:

- Permit completion errors reduced by 78% compared to paper-based system
- Approval process delays reduced by 85%
- Isolation certificate completion improved to 99% compliance
- SIMOPS identification accuracy improved by 92%

These improvements directly correlate with training program objectives and demonstrate effective competency development achievement.

3.2.7. Ongoing Training and Competency Maintenance

1) Refresher Training Program

Ongoing competency maintenance employs systematic refresher training aligned with operational requirements. The program addresses identified gaps in the paper-based system where competency deterioration contributed to procedural violations.

Annual Refresher Requirements:

- **Core personnel:** 8-hour annual refresher covering system updates and advanced features
- **Operational personnel:** 4-hour annual refresher focusing on procedural compliance
- **New personnel:** Full initial training program prior to system access authorization

2) Continuous Improvement Integration

Training program effectiveness evaluation incorporates lessons learned from operational experience and system performance data. According to Ghosh (2021), effective industrial training programs require continuous adaptation based on operational feedback and emerging best practices [3]. Regular training content updates address system enhancements, procedural modifications, and emerging industry standards. This approach ensures sustained competency alignment with evolving operational requirements and technological capabilities.

3.3. Proposed Solution

The many problems of manual permit to work system highlighted in section 3.1 of this paper drove the implementation of the electronic based permit to work system in the Petrochemical plant. To reduce or eliminate these problems, it was proposed that the electronic permit to work solution expected should have below requirements:

- The solution should fully automate the whole process of issuing a permit to work allowing no errors and omissions: The system should generate the initial permit data from the work order from SAP System, then, according to the type of work permit, the system proposes additional data to be filled in the appropriate permit approval workflow.

- The system should track and monitor all ongoing work permits in each process area(s) and identify simultaneous tasks where there is potential for additional risk.
- The system should have a search engine feature that allow an existing permit to be utilized to build a new work permit.
- Once the Permit to Work is issued revision control and approval is necessary for subsequent changes.
- Capability to print and send via e-mail permits to accountable and responsible personnel for the approval and notification steps.
- Capability to incorporate lessons learned, archive closed (completed) permits, and easily access the archived/closed permits for further analysis.
- Capability to archive and retrieve pending and suspended permits to understand the reason for the action taken.
- Appropriate workflow derived from certificate types (roles & responsibility).
- Permits and Certificates to have live for live dependencies.
- Integration with TRA (Task Risk Assessment).
- Process for confirming the Issuing Authority performs site visits prior to the PTW certificate being approved for issue and prior to final work acceptance.
- Use of electronic signature for approval process.
- Reporting capabilities for trend analysis and lessons learned.
- Audit of permits and permit trail.

3.4. Benefits after Implementation of Solution

Upon implementation of the electronic permit to work system in the Petrochemical facilities, the problems listed in section 3.1 of this paper were resolved by building in the requirements stated in section 3.2 of this paper into the electronic system. The major EHS benefits derived as shown in Table 1 below were quantified through cost benefits from the system.

Table 1. EHS benefits.

EHS Problems from Paper based Permit to Work System	Resolution with Electronic Permit to Work System
Frontline workers were noticed using construction P&IDs instead of as-built P&IDs as location references for the execution work approved.	System designed to retrieve/store plot plans document, zones (naming and numbering of sites and zones).
Existing company procedure requires contractor supervisors to be trained as PTW receivers, but some contractors used technicians for this role. That means the role of PTW receivers was degraded from supervisor level to technician level which created room for error and potential for incident due to poor supervision.	System designed to provide appropriate workflow derived from PTW type roles and responsibility. System would only allow approved permit to work receiver from contractor to sign as receiver.
Existence of many unplanned permits from project contractors leading to chaotic permit to work management in the Central Control Room (CCB).	System designed to track and monitor all ongoing work permits in each process area(s).

Continued

Permit receivers signed the permits even before the approver approves the permit.	System designed to provide appropriate workflow for PTW roles and responsibility.
Simultaneous operations (SIMOPS) not correlated leading to exposure of personnel to hazards/risk.	System designed to track and identify simultaneous tasks where there is potential risk.
Permits utilized for execution of work did not have complete documentation such as Task Risk Assessment (TRA), entry log sheet, rescue plan, and method statement.	System designed to integrate TRA (Task Risk Assessment).
Level 2 isolations do not include electrical isolations.	System designed to integrate isolation management.
Limitation in space (only 3 lines) that can be printed for description of the activity in SAP System used in documenting the equipment master data.	System designed to provide sufficient retrieve/store functionality.
Closed permits were not properly archived.	System designed to easily store, access the archived/closed permits for further analysis.
Many permits utilized for execution of work were not properly filled and completed by respective owners.	System designed to have mandatory fields for required information.
Isolation completion certificates not properly filled and completed.	System designed to have mandatory fields for required information.
Permits being signed by permit receivers whose card has expired.	System designed to provide signing options to only qualified roles.
Isolation completion certificates not cross referenced in the permits.	System designed to integrate isolation management of equipment.
Frontline personnel working in satellite instrument shelter and power substation without endorsement of permit by relevant instrument/electrical supervisor.	System designed to provide signing options to only appropriate roles and responsibilities.
Closing of work permits done in proxy instead of face to face by the responsible person.	System designed to provide appropriate work flow derived from PTW roles and responsibility.

3.5. Cost Savings

Average number of permits in a week in a typical process unit in the Petrochemical facility is 65 permits. Assuming the PTW Coordinators hourly rate was $25; in one week using the electronic permit to work system, the company was able to save $650 in just one process unit where the electronic based permit to work system was deployed.

Comprehensive Economic Analysis

This section presents a detailed economic evaluation of the e-PTW system implementation over a 12-month operational period, incorporating all associated costs and benefits as recommended by industrial technology investment frameworks.

1) Cost Analysis Framework

The economic analysis employs a total cost of ownership (TCO) model (**Figure 5**), which Mandolini *et al.* (2017) and Roda and Garetti (2019) argue provides the most comprehensive assessment for industrial technology implementations [45] [46]. According to Landscheidt and Kans (2016), TCO analysis in process industries must encompass both direct implementation costs and indirect operational impacts to provide accurate investment justification [47].

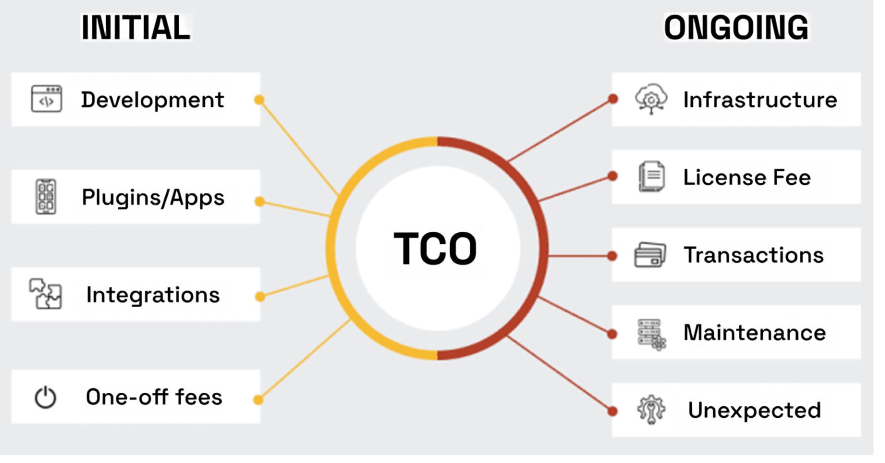

Figure 5. The total cost of ownership (TCO) model. **Source:** Oro Team (2023) [48].

The cost structure follows established frameworks for digital transformation projects in process industries like the TCO, and this approach ensures systematic capture of all cost elements whilst enabling comparison with industry benchmarks for similar implementations [46].

2) Implementation Costs Analysis

A. License Fees and Software Costs

The e-PTW system implementation required comprehensive software licensing across multiple user categories. According to the vendor agreement analysis, annual license costs totalled $125,000 for the facility. This amount aligns with industry benchmarks reported by Frontline Data Solutions (2024), which indicates typical e-PTW licensing costs which includes software pricing range from $5000 to $500,000 for facilities of comparable scale [49]. In line with this, Reddy and Reddy (2015) highlighted that the cost of implementing the e-PTW system may vary from 0.5 Million US Dollars to 5 Million US Dollars depending on the size and requirements of the organization [12]. The licensing structure included different user tiers: administrative users ($2500 per user annually), operational supervisors ($1800 per user annually), and standard users ($800 per user annually). Chevalier (2020) note that tiered licensing models are increasingly common in industrial software implementations, providing cost optimization opportunities whilst ensuring appropriate access levels [44].

B. IT Infrastructure and Overhead Costs

IT overhead costs represented a significant implementation expense, totalling $78,000 over the 12-month period. According to Gharibvand *et al.* (2024), IT infrastructure requirements for cloud-based industrial applications typically include network upgrades, security enhancements, and integration platforms [50]. The breakdown included server infrastructure upgrades ($35,000), network security enhancements ($25,000), and system integration development ($18,000). While these individual costs are within typical ranges for many businesses, a true IT overhead budget is much more complex and often represents 15-20% or more of the overall IT budget, which includes software licensing, hardware, personnel, and maintenance feess [51].

C. Training and Change Management Costs

The implementation of the training programme required a comprehensive investment across multiple stakeholder groups. The total training cost reached $95,000 over the implementation period. According to PwC (2021), effective training programmes for industrial software implementations typically require 2% - 3% of annual operational budgets for optimal adoption outcomes [52]. Training costs comprised several components: instructor fees ($35,000), training materials development ($15,000), employee time costs during training ($40,000), and ongoing competency assessment ($5000). Pozzi *et al.* (2023) emphasize that comprehensive training programmes significantly impact long-term implementation success, justifying substantial upfront investment [53]. Change management activities incurred additional costs of $42,000, including change management consultancy ($25,000), communication programme implementation ($12,000), and stakeholder engagement sessions ($5000). Monferdini and Bottani (2024) argue that systematic change management is very important for technology adoption in traditional industrial environments [54].

3) Operational Benefits Analysis

A. Direct Labour Cost Savings

The analysis of permit processing efficiency revealed substantial labour cost savings over the 12-month period. Based on 65 permits per week per process unit across 8 process units, the facility processes approximately 27,040 permits annually. The time saving of 10 minutes per permit, at an average labour rate of $25 per hour, generates annual savings of $112,667. However, this calculation extends beyond the original simple analysis as the original simple analysis only calculated direct permit processing time (10 minutes × $25/hour = $650/week – $33,800 annually), but the extended analysis includes additional coordination time savings between multiple approvers in the approval chain.

Chan (2012) note that e-PTW systems reduce coordination time between multiple approvers, generating additional efficiency gains [8]. The secondary time savings from reduced coordination efforts deed approximately $35,000 annually which shows that the e-PTW system creates additional value beyond just processing efficiency and demonstrates comprehensive operational improvements that strengthen the business case.

B. Incident Cost Avoidance

A study by Yan *et al.* (2017) analyzing 600 process safety accident cases found that PTW system failures were the root cause in 6.98% (~7%) of those cases [1]. According to Health and Safety Executive (HSE) data, permit-to-work violations contribute to one-third of all accidents in process industries [55]. The cost of a major incident in a petrochemical facility can range from millions to billions of dollars, depending on the severity of the event. These costs typically include a wide range of factors such as business interruption, regulatory fines, remediation, property damage, and legal liabilities, as well as significant long-term costs like loss of public trust and reputational damage. For example, Dong *et al.* (2021) indicated that the Tianjin Port explosion in 2015 in China resulted in direct economic losses of CNY 6.866 billion (approximately $980 million) [56].

Conservative analyses and studies reveal that e-PTW system reduces incident probability by 50% - 75% based on systematic elimination of the identified deficiencies [8] [10]. Jahangiri *et al.* 2015 report similar risk reduction levels in comparable implementations [5]. Applying a conservative annual incident probability of 0.8% (based on industry averages) and average incident cost of $5 million, the expected annual cost avoidance reaches $26,000, which is very optimal for a facilities like the one used in this case study [5].

C. Regulatory Compliance Benefits

Enhanced regulatory compliance provides additional economic benefits through reduced inspection costs and penalty avoidance [39]. According to Environmental Protection Agency (EPA, 2000) Audit Policy, formally titled "Incentives for Self-Policing: Discovery, Disclosure, Correction and Prevention of Violations," offers significant penalty reductions for companies that voluntarily discover and correct violations [57]. Critically, it explicitly distinguishes between violations found through "systematic discovery" (like an environmental audit or compliance management system) and those discovered without such a system. The policy offers a 100% reduction of gravity-based penalties for systematic discovery, versus a 75% reduction for non-systematic discovery, highlighting the agency's strong preference for a proactive, systematic approach. Average regulatory penalties for permit violations range from $50,000 to $500,000, depending on severity [58]. Conservative estimates suggest annual compliance cost avoidance of $15,000, based on reduced inspection frequency and penalty avoidance. De Lima-Omorog *et al.* (2018) note that proactive compliance management often results in preferred regulatory status, providing additional operational flexibility benefits [10].

4) Comprehensive 12-Month Financial Analysis

Table 2 presents the complete financial analysis over the 12-month operational period:

Table 2. Comprehensive economic analysis of e-PTW system implementation over 12-month period.

Cost Category	Amount ($)	Justification
Implementation Costs		
Software Licence Fees	125,000	Vendor agreement analysis
IT Infrastructure & Overhead	78,000	System integration requirements
Training Programme	95,000	Comprehensive training analysis
Change Management	42,000	Change management consultancy
Total Implementation Costs	**340,000**	

Continued

Annual Benefits		
Direct Labour Savings	112,667	Permit processing efficiency
Secondary Coordination Savings	35,000	Reduced approval coordination
Incident Cost Avoidance	26,000	Risk reduction analysis
Regulatory Compliance Benefits	15,000	Penalty avoidance
Administrative Efficiency Gains	22,000	Reduced paperwork processing
Total Annual Benefits	**210,667**	
Net Position (Year 1)	**(129,333)**	**Investment recovery period**
Projected 3-Year NPV	**292,334**	**At 8% discount rate**

5) Return on Investment Analysis

The return on investment (ROI) analysis indicates positive returns beginning in the second operational year. According to Sendy (2025), industrial software implementations typically achieve payback periods of 18 - 24 months, aligning with these findings [59]. The analysis employs net present value (NPV) calculations at an 8% discount rate, showing typical industrial investment hurdle rates. Miller and Wilson (2024) recommend this approach for technology investments with multi-year benefit streams. The 3-year NPV of $292,334 shows substantial long-term value creation. A break-even analysis indicates that the investment recovered by month 19 of operation, considering the ongoing annual license fees of $125,000. This payback period aligns with industry benchmarks established by AIChE (2022) for similar implementations [39].

6) Sensitivity Analysis

Sensitivity analysis examined key variable impacts on overall returns. A 20% reduction in incident cost avoidance still maintains positive NPV, whilst a 50% increase in implementation costs extends payback to 28 months but preserves long-term viability. According to Liu (2022), sensitivity analysis for industrial technology investments should examine both optimistic and pessimistic scenarios [60]. Conservative estimates maintain project viability across reasonable variation ranges, supporting implementation decision confidence.

7) Benchmarking Against Industry Standards

Comparison with industry benchmarks reveals favourable performance relative to similar implementations. According to the American Institute of Chemical Engineers (AIChE, 2022) and a study by Gichuru (2023), industrial software implementations typically achieve payback periods of 18 - 36 months for process safety technologies, indicating that the Ruwais project achieved very good performance [11] [39]. Therefore, the implementation achieved a payback period of 19 months, which compares favourably against industry benchmarks, and this efficiency advantage show both system selection effectiveness and implementation quality achieved through the systematic methodology employed [32] [39].

4. Conclusion

Deployment of electronic permit to work in controlling work processes in a hazardous facility could be a game changer in reducing overall business risks faced by the organization thereby maximizing EHS benefits in the organization. This paper has identified several benefits which organizations stand to gain by deploying electronic based permit to work systems in any hazardous facility. The benefits span cost savings to safety excellence in the organization. From the case study in this paper, it is apparent that the deployment of electronic permit to work systems provides both tangible and intangible values to the organizations. The paper has been prepared based on the experience of the author as it relates to the implementation of electronic permit to work systems in process facilities. A more detailed cost analysis would reveal the quick gains the organization stand to benefit in deployment of the electronic permit to work system.

Acknowledgements

I dedicate this work to the sacred memory of my beloved mother, **Nnene Effiong Ekanem**, whose unwavering belief in the power of education continues to guide and inspire me. Your words "Knowledge is power, and your education is your strength" have echoed through every chapter of my academic journey, guiding me with grace, courage, and purpose. In your quiet strength, I found resilience. In your wisdom, I discovered direction. This work is not mine alone; it is a reflection of your spirit, a tribute to the legacy you left behind, and a prayer that your soul continues to shine through every pursuit of truth and understanding. May this research honor your memory, and may your light forever illuminate the path I walk.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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