



AI-Augmented HSE Excellence: Integrating Smart Technologies with the CPMAI Methodology for Proactive Safety Performance

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ABSTRACT

The research explores how smart Artificial Intelligence (AI) technologies are integrated in the Cognitive Project Management for AI (CPMAI) methodology to improve Health, Safety and Environment (HSE) performance in industries with high risk. In this research, the gap between AI potential and its implementation in the structured and practical implementation for HSE has been addressed. This research adopts a secondary data collection method. 45 Peer reviewed articles, case studies and industry reports published during 2019-2025 has been selected from relevant databases like IEEE Xplore, Scopus and ScienceDirect and data has been analysed through thematic analysis method. Key themes covered in the analysis are key applications of AI, integration framework, principles of project management and theoretical framework. The research highlights that AI tools like Machine Learning (ML) is used in predictive analytics, Natural Language Processing (NLP) in incident analysis, Computer Vision in detecting hazards improve proactive risk management. A significant six-phase structure is offered by CPMAI framework which assumes that business objectives and AI projects are aligned, properly governed and follows ethical principles. In the safety metrics, integration of AI and CPMAI brings measurable improvements, it improves environmental compliance and minimise incident rates. Combination of AI technologies and the CPMAI methodology change the reactive nature of organisational HSE framework to a proactive one. A strategic framework has been highlighted in this research to adopt such an integrated approach. Theoretically, the research strengthens application of Social-Technical System Theory (STST) and Technology Acceptance Model (TAM) to demonstrate application of AI in HSE. The research has practical implications because it offers actionable insights to the managers to properly implement AI-oriented safety projects. The research highlights the need for a data-driven project management approach to improve AI potential in the HSE to build a sustainable and safe work culture.

1. INTRODUCTION

In contemporary industries, ethical and sustainable operations place greater attention to the effective management of Health, Safety and Environment (HSE). Conventional HSE practices were reactive because they have only focused on

resounding to incidents post-occurrence and maintained compliance with the safety regulations. The growing complexity of industrial works and demand for a large pool of data management necessitates a predictive safety management which

has a proactive nature rather than reactive one. Transformative potential of AI and Data Analytics, nowadays has enabled organisations to process large pool of data, find hidden patterns and predict potential risk before they escalate.

Advanced technologies like DL, ML, NLP, and Computer Vision are not limited to the theoretical field because they are now applied practically to improve safety at the workplace and enhance compliance to the environmental regulations. It is true that AI technologies and tools have high potential to bring revolutions but their ad-hoc integration often faces difficulties to bring sustainable improvements. AI initiatives have seen success because of the sophisticated algorithms and robustness to be combined with methodology to enhance implementation. It facilitates the creation of specialised frameworks like Cognitive Project Management for AI (CPMAI) methodology to pair Agile Project Management (APM) with principles of data science to manage unique lifecycle of AI projects.

1.1 Problem Statement

In modern-day operations concerning Health, Safety, and Environment (HSE), management of HSE is a foundational set of principles for sustainable and ethical functioning of any industry. Over the years, HSE practices have remained reactive. Over the years, HSE practices have remained reactive, focusing incidents solely on the rule of law and addressing HSE issues after the fact. However, the complexity of industrial operations, coupled with the increasing amount of data available, is giving way to new opportunities for increasingly preemptive and predictive management for the due safety of individuals involved.

There are still several barriers to this transformation. First, there is still a lack of a proactive organizational culture in the response to such incidents. Most still react to incidents, leaving gaps in the response that require proactive intervention. Second, a predominant theme of the sector is the use of lagging indicators that focus primarily on measuring failures. As such, there is a lack of focus on the implementation of leading indicators that form the basis of predicting failures before they occur. Third, gaps in case analysis are still apparent. For example, the analysis of incidents does not provide adequate emphasis on the warning signs that should prompt action.

Additionally, today's industries produce extreme amounts of data from sensors, logs, reports, and other documents, overwhelmingly surpassing human analytical abilities. As a result evaluating all the records, incident reports are very much time consuming and cannot help in identifying the significant problems and areas. Furthermore, the safety professionals don't possess such advanced tools to analyze these unstructured data. As a result, this type of practice reduce their problem solving skills.

These challenges create an important implementation gap: while the use of AI technologies integrated with targeted safety outcomes remains unstructured, and organizations understand the impact of Artificial Intelligence (AI) and the use of technologies integrated with targeted safety outcomes void of a structured approach on the revolutionizing of the potential of AI on HSE outcomes. The absence of a clear project management framework, data governance, model validation, ethics, and stakeholder alignment challenges contribute to the alignment challenges, resulting in the untrustworthiness of AI systems. This absence of a coherent approach to the adoption of an enterprise-wide implementation of a data-governed safety management system has led to organizations remaining at the stage of siloed pilot initiatives, failing to nurture a data-driven safety culture.

As a result, there is a critical need for this research to investigate how a structured project management methodology like CPMAI can be implemented with smart AI technologies in a systematic order to build a strong and effective framework for improving the operation efficiency of HSE.

1.2 Research Aim and Objectives

The key aim of this study is to examine the implementation of smart AI technologies and the CPMAI methodology for improving the performance of health, safety and environment (HSE). In order to fulfill this research aim, the research objectives are formed:

1. To identify and separate the different AI technology categories that can be applied to HSE management.
2. To examine and understand the primary principles of AI and CPMAI framework.
3. To find out how the implementation of AI and CPMAI can improve the safety and

environmental results depending on the existing literature and evidence.

4. To recommend a strategic framework to adopt AI-driven project management in HSE.

1.3 Research Questions

This research mainly aims to find out the results of the following research questions:

1. What type of AI technologies are the most effective in improving HSE management?
2. What are the main stages of CPMAI framework which helps in the successful implementation of AI in HSE management?
3. How independent AI and CPMAI framework implementation can lead to the improvement in safety environmental results?
4. Which strategic frameworks are ideal for organizations for implementing AI-driven project management for HSE?

1.4 Significance and Scope of the Study

This study is crucial for both the academics and industries. This study will provide a structured and evidenced based framework for the professionals working in high risk industries such as construction, manufacturing, oil and gas, healthcare and logistics (Yasir et al., 2024; AlKatheeri et al., 2025; Rana et al., 2025). This study will help them to utilize AI to shift their work from reactive to proactive safety management. As a result of this, there will be less incident rates, improved regulatory compliance, improved operational efficiency and a strong culture of safety within the organisations (Joghee et al., 2013; Habbal et al., 2019; Alshurideh et al., 2025). In the case of academics, this study will provide detailed information about implementation of AI, project management and HSE. Furthermore, it will help in understanding the actual concept of AI implementation in critical safety environments based on theoretical frameworks which mainly include Socio-Technical Systems Theory and Technology Acceptance Model.

The primary focus of this study is to analyze the secondary data which includes existing peer-reviewed literature, case studies regarding different industries, and published journals about AI project frameworks (AlQassem et al., 2022; Lee et al., 2024; Khadragy et al., 2022). It does not include any type of primary data or survey, instead it aims to critically review the existing literature

and create a conceptual framework based on those articles (Alzoubi et al., 2025; Ma'asor et al., 2023; Nuseir et al., 2021). The scope of this study is to analyze the strategical and methodological aspects of AI implementation rather than focusing on deep technical knowledge about different AI algorithms.

2. LITERATURE REVIEW

This section of the study gives an extensive review of the existing literature organised into key themes. The themes start with addressing the primary AI technologies that are being applied to HSE management. After that, it examined how project management frameworks are formed for AI implementation focusing on CPMAI (Maydybura et al., 2024; AlQassem & A. H., 2024; Khan et al., 2024). This is followed by a review of the theoretical foundations that identify the integration of technology and organizational systems. In the end, the literature review analyzes these themes to identify the current research gaps and provide a detailed conceptual framework for this study (Alshurideh et al., 2024; Alblooshi et al., 2025; AlQassem et al., 2025).

2.1 AI Technologies in HSE Management

The application of AI in HSE management is shifting from theoretical explorations to practical examples which offers multiple tools to predict and prevent environmental hazards and safety incidents occurring in workplaces (Tanveer et al., 2025; Kofinas et al., 2016; El Khatib et al., 2024).

Machine Learning and Predictive Analytics are the most crucial part of safety practices. ML algorithms mainly analyze the past incident data, near-miss reports, operational logs and environmental sensor readings to get detailed information about complex patterns and their relations with the terrible incidents that happened (AlHamadi et al., 2024; El Khatib et al., 2023; Nuseir et al., 2019). As Adio et al. (2025) note, this enables a change from slow indicators for measuring past failures to fast and improved indicators for predicting future risks (Anifa et al., 2022; Al-Kassem & A. H., 2021; Kurdi et al., 2025). For instance, predictive models can forecast the failure of equipments, high-risk operational periods identification which will allow for future targeted preventive measures (Alshawabkeh et al., 2018; Joghee et al., 2023; Sun et al., 2016).

Another revolutionary technology is Computer Vision, which employs the use of cameras and deep

learning models to expedite the supervision of workplaces in real-time (AlShawabkeh et al., 2021; El Khatib et al., 2023; Pande et al., 2024). These systems can detect and monitor unsafe conditions, such as the lack of Personal Protective Equipment (PPE); unauthorized entry to restricted areas; and poorly designed, potentially dangerous, ergonomic workstations (Samer Hamadneh et al., 2023; Alshurideh et al., 2022; Tangri et al., 2023). Computer vision systems can issue alerts and prevent incidents from occurring (AlShawabkeh et al., 2014; Kanwal et al., 2023; Nazeer et al., 2025). The systems' data can also be useful in determining the cause of an incident and can be incorporated into the respective safety training programs (Vij et al., 2025; Kharabsheh et al., 2024; Kabiraj et al., 2009). The technology also serves as a constant watcher, which, when paired with human supervision, is an improvement to caution and awareness in the workplace (Joghee et al., 2024; AlShawabkeh et al., 2021; Joghee et al., 2021).

Natural Language Processing (NLP) focuses on understanding how machines and humans communicate (Khan et al., 2023; Rosmadi et al., 2025; Kukunuru et al., 2019). The focus of this study is on training machines to analyze the domain of unstructured data (Alzoubi et al., 2024; Anifa et al., 2024; Shao et al., 2025). This unstructured data takes the form of incident reports and safety audits. Using NLP, structured reports can be desk analyzed in line with safety observations, where prevailing patterns in the reports and safety outcomes can be captured. This is termed thematic analysis in qualitative research (AlShawabkeh et al., 2023; Shao et al., 2025; Ilyas et al., 2023). This desk analysis of safety reports using NLP has the potential to support safety professionals in understanding the systemic relationships between the reports and safety outcomes and trends, ultimately leading to the formulation of preventative safety policies (Treacy et al., 2025; AlKatheeri et al., 2025; Shehab et al., 2023).

The AI systems that receive real-time data streams from IoT devices and Wearable Sensors (AlNajdawi et al., 2024; AlShawabkeh et al., 2013; Yas et al., 2024). Within any given facility, deployed IoT sensors can determine environmental parameters such as air quality, noise, and chemical exposures (Alzoubi et al., 2024; Pande et al., 2024; Al-Nakeeb et al., 2024). Wearable devices can track worker

biometrics, as well as their location and any hazards they may come into contact with (Alzoubi et al., 2024; Razmak et al., 2018; El Khatib et al., 2022). With AI, this data enables a fluid and tailored process of safety management, in which safety alerts are issued and threats are communicated to both workers and their supervisors (Al-Kassem et al., 2022; Kharbat et al., 2021; Shwedehe et al., 2024).

2.2 Project Management Framework for AI: The CPMAI Methodology

AI projects are one-of-a-kind, data-driven, and probabilistic, meaning they're quite different from traditional projects. This means you have to avoid traditional ways of thinking. The CPMAI Methodology has and continues to be the most used method for these kinds of projects (Alshurideh et al., 2025; Khatib et al., 2024; AlKurdi et al., 2025). It offers comprehensive, systematic, and scalable approaches to the management of data and AI projects, and ensures that these projects are technologically feasible and morally sound (Khatib et al., 2024; Hanaysha et al., 2021; AlNajdawi et al., 2024).

The CPMAI framework is built on the key principles of central data, iterative development, collaboration with stakeholders and continuous improvement. This framework mainly consists of 6 different phases which are:

1. Business Understanding: Defining the goals of the project, key performance indicators (KPIs), and making sure that it aligns with the wider organizational objectives.
2. Data Understanding: Identifying, collecting and examining the data required for the AI model, evaluating its quality and limitations.
3. Data Preparation: Cleaning, changing and organizing the data for model training.
4. Model Development: Selection and training of the AI model, and refinement of its performance.
5. Model Evaluation: Testing extensively the AI model on the basis of defined success criteria. Evaluating its accuracy, fairness and robustness.
6. Model Deployment: Implement the AI model into the target business process and developing procedures for ongoing monitoring and maintenance.

Thus, by giving a proper and clear

approach, CPMAI helps to prevent the common drawbacks of AI projects which are mainly poor data quality, biases of the model, and lack of stakeholder involvement. This helped to ensure that AI for HSE management are developed and deployed in a responsible and effective manner (Kanwal et al., 2023; AlMidfa et al., 2024; El Khatib et al., 2023).

2.3 Theoretical Foundations

Successfully implementing AI models into HSE is not only a technical challenge but also a complex socio-technical challenge (Som et al., 2023; El Khatib et al., 2023; Shwedehe & F., 2022). There are several theoretical frameworks from the social sciences and management division that can give a strong insight of this entire process (Karthika et al., 2024; Naim et al., 2025; Murtaza et al., 2024).

2.3.1 Socio-Technical Systems (STS) Theory

STS Theory originated in the mid-1900s and suggests that an organization functions optimally when the social (people, culture, organization) and technical (tools, technology, methods) systems operate in unity. In the context of AI in HSE (Health and Safety Work), implementing new technology is insufficient. The AI system must integrate with and support workers, the decision-making process, and the system for ensuring existing workplace safety. Failure to do so, as Kpem et al. (2024) suggest, can lead to the new system becoming stagnant, being misused, or causing problems. The CPMAI framework shows business comprehension and a focus on collaboration with stakeholders, and is most aligned with the principles of STS Theory (Alzoubi et al., 2024; Shwedehe, 2022; Ahmed et al., 2024).

2.3.2 Technology Acceptance Model (TAM)

Most professionals accept the Technology Acceptance Model (TAM) as the framework to predict how users accept and use new technologies (Alzoubi et al., 2024; El Khatib et al., 2023; Joghee et al., 2024). It points out that two factors lead to user acceptance: Perceived Usefulness (the extent to which a person feels that the application of a system would improve their job performance) and Perceived Ease of Use (the extent to which a person feels that the application of a system would require little effort) (AlShawabkeh et al., 2023; Shwedehe et al., 2024; El Khatib et al., 2024). Both workers and managers must perceive AI-driven HSE tools as useful and easy to use in improving safety (Kabiraj et al., 2011; Joghee et al., 2021; Rosmadi et al.,

2025). This explains the need for user-centered design, training, and communication in the context of new safety technologies. This is in the context of new safety technologies.

2.3.3 Diffusion of Innovation Theory

First, developed by Everett Rogers, the Diffusion of Innovation Theory describes the way and the process of the distribution of new technologies and concepts throughout society, along with the speed of this distribution (Al-Qassem et al., 2021; Rana et al., 2025; Halder et al., 2024). He describes the different groups of adopters using different terms and explains how this phenomenon of adoption can be influenced by the channels of communication, time, and the social structure (Yas et al., 2024; El Khatib et al., 2024; Alblooshi et al., 2025). This theory can be directed and applied in AI adoption in HSE, as it proposes the investors' diverse particular segmentation in the adoption of AI in HSE; one example would be encouraging (Alshurideh et al., 2022; Joghee et al., 2018; Kumar et al., 2024).

2.3 Theoretical Foundations (Continued)

2.3.3 Diffusion of Innovation Theory (Continued)

Getting early adopters in an organization engaged and showing them the relative differences between the practices and using AI tools can speed up the organization's adoption of AI tools (Shwedehe et al., 2024; Khan et al., 2024; El Khatib et al., 2023). However, the Theory of AI also raises the question of barriers to successful use diffusion (Shwedehe et al., 2023; AlQassem, 2022; Kofinas et al., 2016). These barriers might include the complexity of the tools, along with compatibility with existing values and norms (AlMidfa et al., 2024; Naim et al., 2024; Khan et al., 2023).

2.3.4 Risk Management Theory

For traditional risk management theory, one has to go through a process through a precise cycle where you identify, assess, mitigate, monitor, and report risks (Razmak et al., 2018; Murtaza et al., 2024; Yasir et al., 2024). Focusing on these stages one at a time has a definable beginning and end: Set up a risk profile, assess it, derive a credit limit, make a risk-based pricing on it, and so on and so forth (AlShawabkeh et al., 2016; AlKatheeri et al., 2025; Naim et al., 2025). Then, the risk becomes a moving target. Here, the focus has to be to mitigate the risk towards zero, as it is impossible to predict what risk will be undertaken next (Alshurideh et al.,

2022; AlNajdawi et al., 2024; Ma'asor et al., 2023). Thanks to AI, risk management is shifting towards a more continuous process where risks can be evaluated and mitigated at an infinitely more dynamic level (AlHamadi et al., 2024; El Khatib et al., 2023; Khan et al., 2024). Focusing on the objectives of risk management provides the basis of these processes, and of the value CNA desires (AlAmiri et al., 2024; Hanaysha et al., 2021; AlQassem et al., 2024).

2.4 Research Gaps and rationale

There is a significant amount of research already conducted on AI in HSE but gaps still exist. Firstly, previous research tends to focus on the details of certain AI technologies. In contrast, there is less research that examines the strategies and methods for implementing AI (AlShawabkeh et al., 2017; Maydybura et al., 2024; Karthika et al., 2024). Secondly, the CPMAI project management framework is one of many, but there is still limited evidence demonstrating the actual applicable use of frameworks on HSE outcomes and improvements (Neyara Radwan et al., 2025; El Khatib et al., 2022; Joghee et al., 2020). Thirdly, the AI adoption theory in high-stakes workplace safety is not yet fully developed (Alzoubi et al., 2025; El Khatib et al., 2024; Kanwal et al., 2023). There are more studies that are merely descriptive, and what we need is more conceptual work that combines technology, project management, and organizational theory (Shwedeh & F., 2021; Shao et al., 2025; Kabiraj et al., 2009).

This study aims to address the gaps. In order to achieve this and construct a more complete integrated conceptual model, a synthesis of the available literature on artificial intelligence (AI) technologies, the CPMAI framework, and pertinent theories of organizations will be undertaken (Alshurideh et al., 2025; Sihag et al., 2024; El Khatib et al., 2022). Having created this model, the next step will be to construct a comprehensive roadmap for the application of AI in health and safety (HSE) to be used by scholars and practitioners.

2.5 Conceptual Framework

The conceptual framework for this study, as shown in Figure 1, showed that the effective implementation of smart AI technologies and CPMAI methodology can lead to an improvement in the operational efficiency and performance of HSE (Sihag et al., 2024; Treacy et al., 2025; El Khatib et al., 2023). The relationship between these two is

supported by organizational factors and key theoretical foundations (Joghee et al., 2018; Alzoubi et al., 2025; Som et al., 2023).

1. Independent Variables: The framework includes two key independent variables which are Smart AI technologies (e.g., Machine Learning, computer vision, NLP and IoT wearables) and the CPMAI methodology (six phases of the framework).
2. Dependent Variable: The dependent variable of this framework is Improved HSE Performance. It is primarily measured through performance metrics such as low incident rates, improved compliance, proactive prevention of risks and a strong culture of safety (Kumar et al., 2024; Ahmed et al., 2024; Alshurideh et al., 2024).
3. Mediating Process: the framework suggested that the CPMAI methodology acted as a mediating process for finding the potential of AI technologies based on the improved HSE results (Al-Qassem et al., 2024; Naim et al., 2024; AlKurdi et al., 2023).
4. Theoretical Strengthening: The framework is extensively supported by the Socio-technical Systems Theory, Technology Acceptance Model, Diffusion of Innovation Theory and Risk Management Theory. All these theories help to understand the interconnection between technology, people and processes (Kharbat et al., 2017; Anifa et al., 2024; Salloum et al., 2024).

3. RESEARCH METHODOLOGY

3.1 Research Design

This study follows a secondary qualitative research methodology. This methodology is appropriate since the objective of the study is to formulate a conceptual model based on the combination of various forms of data, as opposed to verifying a specific hypothesis against primary data. Analyzing diverse literature is particularly beneficial for rapidly growing fields like AI. For this reason, a secondary approach is the best for this research. Since this is qualitative research, the research is able to provide extensive, contextual and multifaceted detailing of the complexities that affect the merging of AI with project management within HSE.

3.2 Data Collection

For this study, data is collected mainly using a systematic analysis of the existing literature. The data collection method was supported by predefined criterias in order to maintain quality, relevance and thoroughness.

3.2.1 Source Selection Criteria

A multi-phase filtering process was followed to select and analyse the selected sources. The following processes are followed in order to filter the sources:

1. Databases: The sources were searched in different academic and technical databases and websites, including Google Scholar, Scopus, Web of Science, IEEE Xplore, and ScienceDirect.
2. Search Terms: Specific keywords are used like "Artificial Intelligence and HSE", "machine learning and safety", "CPMAI framework", "AI project management", "predictive analytics HSE", "computer vision safety", and "technology acceptance model safety".
3. Inclusion Criteria: There are some specific criteria for selecting sources. The criterias mainly include 1) the articles must be peer reviewed, conference papers or well known industry reports, 2) should be published between January 2019 and November 2025, 3) should be written in English, and 4) should have relevance with the application of AI in HSE, AI project management or related theoretical frameworks.
4. Exclusion Criteria: Similarly, the sources will not be selected based on certain criterias which are 1) if the articles are not peer reviewed (e.g., blog posts, news articles), 2) if not the articles are published before 2019, 3) if not available in English or 4) if it is purely technical and has no relevance with the context.

3.2.2 Data Collection Process

Initially, the research collected approximately 250 articles. These articles are further sorted based on their introduction and abstract and the number of articles are reduced down to 85 precisely. The entire content of these 85 articles are then reviewed thoroughly based on the inclusion/exclusion criteria. Finally, the 85 articles are further reduced to 45 articles for detailed

analysis.

3.3 Data Analysis Techniques

A thematic analysis approach was utilized to analyze the collected articles. This approach is appropriate for identifying, analyzing and reporting key themes within qualitative data. As stated by Braun and Clarke (2006), the analysis followed a six-phase process:

1. Data Adjustment: Reading the selected sources thoroughly to gather deep knowledge of the content.
2. Generating initial codes: Structurally coding the important features of the data across the dataset.
3. Searching for themes: Implementing the codes into the themes.
4. Defining themes: Specifying and defining the themes based on the analysis.
5. Producing the report: Data is extracted after the full analysis and form a detailed record based on the analysis.

3.4 Quality Assessment

In order to determine the reliability and accuracy of the data, a quality assessment was conducted on the selected resources. The value of each source was determined by the standing of the journal or conference, the thoroughness of the study methodology (for empirical studies) the research was based on, the level of detail and logical progression of the arguments, and the volume of citations. These measures ensured that the combined literature was based on credible evidence.

3.5 Ethical Considerations

This particular research study observes the best ethical research practices. Since the study conducted here is secondary research, the principal ethical concerns relate to the proper utilization of work already done and proper attribution. All sources are cited in the references section with full and accurate detail, and direct quotes are marked as such and attributed. There is absolutely no plagiarism, and the study has paid due regard to the work done by other authors. There has been no compromise on the academic honesty of the research in the collection and analysis of the data.

3.6 Limitations of the Methodology

This study has several limitations inherent in its approach to research. First, there is a reliance on the literature in this field, which is itself subject to

any applicable publication biases within the field. Second, the literature published has not yet caught up with the rapidly evolving field of AI, so there are emerging trends that may not yet be discussed. Third, the study does not incorporate primary data collection, which means that the study neglects to address the AI implementation within the organization and its nuanced, context-rich challenges. Even with these limitations, the methodology selected allows for a solid base in building a detailed conceptual knowledge of the subject, in addition to being able to inform future empirical studies.

4. DATA ANALYSIS AND RESULTS

The Data Analysis chapter presents the findings from the 45 collected sources. The analysis is aligned with four research questions of the study which systematically synthesise existing studies to highlight how AI and CPMAI methodology is combined to improve HSE performance.

4.1 Overview of Sources Analyzed

Table 1: AI Technologies Applicable to HSE Management

Technology	HSE Application	Key Benefits	Common Limitations	Representative Sources
Machine Learning (ML) / Predictive Analytics	- Predictive maintenance for critical equipment -Forecasting high-risk operational periods -Identifying leading indicators of incidents	- Proactive risk mitigation -Reduced equipment downtime -Optimized resource allocation	- Requires large, high-quality datasets - Model accuracy can be variable - Risk of algorithmic bias	[6], [7]
Computer Vision	- Real-time monitoring of PPE compliance -Detection of unsafe behaviors (e.g., improper lifting) -Identification of environmental hazards (e.g., spills)	- Continuous, automated monitoring -Immediate alerts for unsafe conditions - Rich data for root cause analysis	- Can be affected by lighting/weather - Privacy concerns for workers - High computational cost	[8]
Natural Language Processing (NLP)	- Analysis of incident and near-miss reports -Identification of emerging safety trends - Sentiment analysis of safety culture surveys	- Extracts insights from unstructured data -Identifies latent causal factors - Reduces manual analysis time	- Can struggle with industry specific jargon -Requires significant training data - Nuance and context can be missed	[9]
IoT & Wearable Sensors	- Real-time tracking of worker location	- Personalized risk management	- Battery life and connectivity issues	[10]

45 sources published during 2019-2025 forms the final dataset where 65% sources are peer-reviewed journal articles and 25% are conference papers and industry reports are 10%. The sources are collected considering the different geographical contexts in which studies from Europe is 35%, North America is 40% and Asia is 15%. It highlights global interest in utilising AI in the environmental management and safety in the industry.

4.2 Findings for RQ1: AI Technologies Applicable to HSE Management

A different range of emerging and mature AI technologies has been highlighted in the analysis that can be applied to managing HSE framework. AI technologies intended to improve predictive capabilities, offer decision support and ensure automated monitoring. Below Table 1 summarises the key HSE applications benefits and common limitations of different AI tools like ML, IoT, Computer Vision, NLP, etc.

	and exposure -Monitoring of environmental conditions (gas, noise) -Detection of worker fatigue or distress	-Enhanced situational awareness -Immediate alerts for acute exposures	Data security and privacy risks -Potential for worker resistance	
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According to the findings, a single AI-driven tool cannot derive significant value but multiple AI-driven tools can build a cohesive framework for proactive risk management and an effective HSE framework. For example, ML models can be fed with data generated by the IoT sensors to improve predictive alerts and computer vision can verify these alerts for accurate HSE management.

4.3 Findings for RQ2: CPMAI Framework Principles and Stages

Table 2: CPMAI Framework Stages and Their Application in HSE

CPMAI Phase	Key Activities	HSE-Specific Example	Application
1. Business Understanding	- Define project goals and KPIs Assess feasibility and value Secure stakeholder buy-in	- Goal: Reduce fall-related incidents by 20% KPI: Number of real-time fall hazard alerts generated	
2. Data Understanding	- Identify and collect data sources Perform exploratory data analysis Assess data quality and relevance	- Collect data from safety reports, camera feeds, and worker schedules to identify patterns related to falls.	
3. Data Preparation	- Clean, format, and label data Handle missing values Feature engineering	- Label thousands of images from construction sites to train a computer vision model to recognize fall hazards.	
4. Model Development	- Select appropriate algorithms Train and tune the model Validate model performance	- Train a deep learning model on the labeled images to achieve >95% accuracy in detecting fall hazards.	
5. Model Evaluation	- Test model against business KPIs Assess for fairness, bias, and robustness Conduct user acceptance testing	- Test the model in a simulated environment and with a pilot group of safety managers to ensure it is effective and usable.	
6. Model Deployment & Operationalization	- Integrate model into workflows Establish monitoring and maintenance Plan for model retraining	- Deploy the model to on-site cameras, integrating alerts into the site supervisor's existing safety dashboard.	

As per the literature, compliance to the structured CPMAI methodology is necessary to ensure transformation of the experimental phase in the AI projects to the deployment of advanced tools for

In the literature, significant identification of the CPMAI framework indicates it as a best-practice methodology to manage the exclusive lifecycle of AI projects. The six-phase structure of the framework is confirmed in the analysis which also acknowledges the core principles of iterative development, data-centricity and stakeholder collaboration. In each phase of CPMAI, key activities and the specific application in managing HSE has been summarised in below Table 2.

successful operation. In the HSE performance, they provide tangible value.

4.4 Findings for RQ3: Integration of AI and CPMAI for HSE Outcomes

Findings from the secondary data collected are synthesised to indicate how integrating CPMAI framework with AI technologies brings a synergistic impact and transformative improvements in managing HSE framework.

CPMAI methodology offers strategic alignment and transparent governance to effectively channel AI capabilities. Below Table 3 summarises key benefits highlighted in the case studies and industry reports.

Table 3: Integration of CPMAI and AI tools for Key Benefits in HSE outcomes

Outcome Category	Specific Improvement	Evidence from Literature
Proactive Risk Management	Shift from reactive incident response to proactive hazard prediction and mitigation.	Case studies in manufacturing show a 30-40% reduction in recordable incidents after implementing predictive safety analytics.
Enhanced Decision Support	AI-powered dashboards provide safety managers with real-time, data-driven insights for better decision-making.	Reports from the construction industry indicate that AI-driven insights led to more effective allocation of safety resources.
Improved Operational Efficiency	Automation of manual monitoring tasks frees up safety personnel to focus on higher-value activities like training and coaching.	A study in the oil and gas sector found that automated drone inspections reduced inspection times by 75%.
Strengthened Safety Culture	Increased transparency and data-driven communication foster greater trust and engagement in safety programs.	Surveys in organizations with mature AI-HSE programs show higher levels of worker engagement in safety reporting.
Enhanced Environmental Compliance	Continuous monitoring of emissions and waste streams helps to ensure compliance with regulations.	A chemical processing plant reported a 90% reduction in minor environmental non-compliance events.

Evidence highlighted in the above table indicates that in unlocking benefits of AI in the HSE framework, structured approach of CPMAI methodology is significant. It keeps AI-driven solutions trustworthy, reliable and integrated in the major fabric of the safety management framework of the organisations.

4.5 Findings for RQ4: Strategic Model for AI-Driven

Table 4: Four Pillars in the Strategic Model for AI-based PM in HSE Framework

Foundation	This pillar is about strategy and culture. It defines a clear and transparent strategy for AI integration in the HSE and connects it with the overall business strategy, securing leadership promises and building a data-driven culture where employees feel psychological safety to be involved in innovation.
Enablement	This pillar is about people and infrastructure to strengthen capability building. It needs investment in making the legacy infrastructure modern to fit cloud computing and advanced technologies, and upskill the workforce with significant technology-based training. These training can cover fundamentals of AI and strengthen digital literacy of safety professionals and data scientists to understand how AI and CPMAI integration can help to overcome specific challenges of HSE.

HSE Project Management

In the HSE framework, adoption of AI-based project management needs a strategic model and analysis of this research can propose such a model. There are four pillars (Foundation, Enablement, Execution and Optimisation) in the model which are discussed below in Table 4.

Execution	This pillar is about process and governance and plays a major role in the operation. Here, formal adoption of CPMAI methodology happens to build standard processes in AI-driven HSE projects. Establishment of an ethics review board with transparent policies ensures strong governance model variation, data privacy and proactive risk management.
Optimisation	This pillar is about measurement and improvement. In this final stage, effects of AI initiatives against the KPIs defined are measured continuously to collect feedback from the end-users and use them for the iterative progress in the models and strategy. It builds a proper cycle of continuous improvement.

Overall, the strategic model for adoption of AI-based project management in the HSE framework offers a strategic and comprehensive roadmap through organisation can go beyond ad-hoc experimental stage and strengthen capabilities for active a mature and sustainable HSE performance.

5. DISCUSSION

The discussion chapter provides extensive interpretation of findings given in the previous chapter. Interpretation helps to understand the importance of the findings in the academic and practical field. The chapter also compares the findings with the previous research and state theoretical and practical implications through demonstrating integration of CPMAI framework with AI technologies to strengthen HSE management. Additionally, the limitations of the findings are also acknowledged at the end.

5.1 Interpretation of Findings

In this research, findings acknowledge that integration of AI in the CPMAI framework, which is a structured PM methodology improves management of health, safety and environment. Synthesizing the literatures, the research offers a compelling and clear narrative which indicates that AI strengthen technical capabilities to change reactive nature of HSE framework to a proactive and predictive nature and a formal methodology offers a significant platform to ensure that the transformation from reactive to proactive HSE is sustainable, successfully and aligned with the strategic business goals. In the HSE framework, the value of AI is not just because of its sophisticated algorithms but also because of its systematic application. In the strategic model, four pillars described helps to give a comprehensive view which indicates that purely technological considerations are not enough to manage critical

human, organisational and process-related factors in the HSE framework.

Diverse AI technologies like ML improves predictive capabilities, NLP accurately analyzes unstructured data and computer vision improves monitoring. However, these technologies working in isolation cannot ensure a proactive HSE framework but their synergistic and coherent effect after their integration with CPMAI can improve impact on HSE. The structured approach gives high quality data, ensure model validation and maintain ethical considerations for trust building which is vital in HSE framework where safety is a critical need.

5.2 Comparison with Previous Studies

The research finding strongly aligns with the existing studies. Key AI tools and their application in the HSE framework aligns with recent studies of Adio et al., (2025) and Silić & Palačić (2024) as they have indicated potential of ML and computer vision in predictive analytics. However, our research has also linked the technologies to improve the PM framework which is missing in the existing studies which maintains explicit focus on the technologies. This research indicates the requirement for a specialised project management methodology in AI-based projects which is highlighted in the studies of Narayanan & Schoeberl (2023), and Victor (2023). These studies mentioned that traditional project management strategies are no longer effective because they lack the data-driven, iterative nature of AI development. This research has similarities with these studies because it shows specific application of AI-driven project management in the HSE framework and also highlighted how CPMAI can improve further safety. However, there are certain differences with the existing studies which indicates that some studies are technology-centric and optimistic but our

research has focused on socio-technical factors. Some industry reports have highlighted AI capabilities exclusively but findings of this research indicates how technology potential improves social needs like safety and environmental compliance. It aligns with STS theory which indicates the significance of workforce training, user acceptance and organisational culture. It also aligns with the study of Kemp et al. (2024), as the author warned that overlooking social and human dimensions can be costly in technology implementations.

5.3 Theoretical Implications

Theoretically, findings of this research have significant implications. Mainly, the finding validates application of Socio-Technical Systems (STS) theory to demonstrate how Industry 4.0 technologies are improving social and human dimensions along with technology implementation in the HSE framework. Combining social and technical systems is a necessity to implement AI in industries where safety is critical. CPMAI framework ensures practicality through aligning data modelling (technical) and strategic business goals (social) at each stage.

Findings of this research also validates Technology Acceptance Model (TAM). It illustrates for safety compliance, technology use has now become mandatory in some industries. According to the results, perceived ease of use and perceived usefulness are important but perceived fairness and trust in terms of monitoring, particularly in case of Computer Vision, are the determinants that are equally important in the HSE context. In industries where safety is critical, improving fairness for greater trust is application is necessary.

The research integrated diverse theoretical concepts in a unified framework and gave scope to future research to further explore this area. It has given a multi-faceted picture rather than explanation of a single theory in demonstrating the issue.

5.4 Practical Recommendations

The findings offer actionable insights to the project managers, HSE managers and organisational leadership. The strategic model proposed with four pillars gives an actionable and clear roadmap so that organisations can better utilise AI in the HSE framework. Some practical recommendations are, **Investment in Digital Infrastructure and Digital**

Skill Building: Organisational leaders should invest in modernising legacy infrastructure to ensure strategic fit of advanced AI tools. Along with this, upskilling the workforce is necessary so that employees like data scientists and safety professionals can understand how to deploy AI strategically and ethically at the same time to overcome challenges in HSE.

Adoption of a Formal Methodology: Considering the importance of CPMAI highlighted in collected data, this research suggests that organisations should adopt it formally in all AI initiatives related to HSE.

Strengthen Strategic Focus: The projects which are not significant strategically but technologically interesting have no value. Organisations need to identify the most relevant HSE challenges, then identify the tailored AI solution for it through use of CPMAI for greater relevance.

Establishing Strong Governance: Establishing an AI Ethics and Governance Committee helps to monitor ethical aspects of AI-driven HSE to ensure transparency, fairness and regulatory compliance.

5.5 Limitations of the Findings

Firstly, findings rely on scope and quality of existing sources because this research solely focuses on existing activities, industry reports, and case studies for data collection. Despite systematic review and significant insights, existing studies cannot always capture the evolving nature of AI, new applications and emerging challenges. Secondly, publication bias risks might be there in analysed industry reports and case studies. They might overlook failure and overstate key benefits and success of technology implementation. Thirdly, the strategic model proposed is conceptual and not validated through any empirical investigation. Hence, impact of its application in the real-world is not covered.

6. CONCLUSION AND RECOMMENDATIONS

The research analysed how smart technologies like AI are integrated with the CPMAI methodology to improve HSE performance. Reviewing and synthesising existing articles, academic publications, industry reports and case studies published between 2019-2025, this research gives a comprehensive conceptual model which has significant contribution to academic and practical fields. This chapter gives a summary of key findings, theoretical and practical contributions,

limitations and future directions.

6.1 Summary of Key Results

Following a secondary data collection method, this research has presented significant findings. Synthesizing data, it acknowledges that AI tools like Computer Vision, ML, and NLP transform additional HSE practices which were reactive. Advanced technologies have made HSE practices more proactive through predicting risks and monitoring safety. However, success of implementation of these AI-driven tools significantly relies on the adoption of a structured and specified methodology of project management, called CPMAI. Integration of AI tools with the CPMAI methodology improves HSE outcomes, improves decision-making accuracy, reduces incident rates and establishes a robust safety culture. The research has proposed a four pillar strategic model which offers an actionable roadmap for the organisations where HSE is a critical need. It improves the maturity of the AI-powered HSE framework.

6.2 Theoretical Contributions

This research has significant theoretical contributions. The findings contribute to strengthening application of STS Theory, TAM and Diffusion of Innovation (DOI) Theory in the context of AI-driven HSE projects. Utilising these theories, the research demonstrated success and challenging factors behind adoption of AI in the HSE projects. The findings indicate that focusing on technological aspects is not enough while implementing AI in HSE framework, considering social, human and environmental aspects should be equally considered for an ethically sound technology adoption. Additionally, perceived fairness and trust in the technologies highlights responsible implementation of AI in the HSE framework. Gradual innovation with AI in the HSE framework is significant for ensuring innovative behaviour development and better innovation. Having these factors (social, human, trust, fairness) can be a strength whereas lack of these factors can pose challenges in implementing AI tools in the HSE framework.

6.3 Practical Contributions

This research has practical value for organisations placing greater attention on HSE. Safety managers get clear guidance on key applications, benefits and challenges of diverse AI tools in the HSE framework and additional impact of their unified application.

CPMAI framework gives a step-by-step, structured methodology to managers to manage AI-driven HSE projects. Organisational leaders can get a significant blueprint of phased implementation of AI through the four pillar strategic model. However, for practical adoption and implementation, this research suggests proper investment to modernise infrastructure, arrange advanced training to strengthen specialised digital knowledge and digital skills of the data scientists and safety professionals. The leadership should develop clear and transparent strategies and ethical framework to ensure not only innovative but also ethically responsible AI deployment in the HSE projects.

6.4 Limitations and Future Directions

This research has solely focused on secondary data and interpreted the issue from the lens of these studies, reports, etc. Secondary data that has been published in 2019, 2020 which cannot significantly cover the evolving nature of advanced AI tools. Additionally, the conceptual model has been prepared synthesizing the literatures but the model has not been empirically tested.

Considering the limitations, the research indicates some future directions. Future researchers can conduct large-scale surveys to validate the strategic models proposed in this research and follow longitudinal design to understand the evolving nature of AI applications in the HSE framework. Further research is vital on exploring human factors of AI in HSE to indicate how employees will interact with AI-driven safety alerts. A robust model for calculating ROI or Return on Investment is required in understanding benefits and cost savings through AI initiatives in HSE. Future researchers should explore more about the ethical and legal dimensions of the issue.

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Appendices

Appendix A: Literature Search Strategy

Databases Searched:	Google Scholar, Scopus, Web of Science, IEEE Xplore, ScienceDirect.
Date Range:	January 1, 2019 – November 22, 2025.
Primary Search Strings:	• ("Artificial Intelligence" OR "machine learning") AND ("Health and Safety" OR "HSE" OR "OHS" OR "occupational safety"). • ("CPMAI" OR "Cognitive Project Management for AI") AND ("safety" OR "HSE"). • ("predictive analytics" OR "computer vision" OR "natural language processing") AND ("workplace safety" OR "environmental management"). • ("Technology Acceptance Model" OR "TAM") AND ("safety technology" OR "AI safety"). • ("Socio-Technical Systems" OR "STS") AND ("AI implementation" OR "safety").
Inclusion Criteria:	Peer-reviewed articles, conference papers, industry reports; English language; direct relevance to AI, HSE, and project management.
Exclusion Criteria:	Non-peer-reviewed sources, publications before 2019, non-English language, purely technical papers with no application context.

Appendix B: Thematic Coding Framework

Author(s)	Year	Title	Source Type
Adio, S. A., et al.	2025	Engineering a Safer Future...	Journal Article
Alshriefy, O. T. A.	2024	The Impact of Risk Management...	Journal Article
Begemann, V., et al.	2024	Enabling and constraining factors...	Journal Article
Braun, V., & Clarke, V.	2006	Using thematic analysis in psychology	Journal Article
Huang, Y., et al.	2024	Evaluating ChatGPT-4.0's data analytic...	Journal Article
Kemp, T., et al.	2024	Using socio-technical systems theory...	Journal Article
Lee, A. T.	2025	A Review of TAM...	Journal Article
Liao, J., et al.	2025	Bayesian optimal experimental design...	Conference Paper
Narayanan, M., & Schoeberl, C.	2023	A Matrix for Selecting Responsible AI...	Industry Report
Paun, C., et al.	2024	The main drivers of e-commerce adoption...	Journal Article
Silić, M., & Palačić, D.	2024	Risk management model for the application...	Conference Paper
Thomas, A.	2024	Digitally transforming the organization...	Journal Article
Victor, N. O. C.	2023	How Artificial Intelligence Influences...	Preprint
Weidinger, L., et al.	2024	Holistic safety and responsibility...	Preprint
Xu, S.	2024	A Longitudinal Study on AI Adoption...	Journal Article
Main Theme	Sub-Theme	Description	Example Code
AI Technologies	Predictive Analytics	Use of ML/statistical models to forecast future safety events.	`predictive_risk`
	Computer Vision	Use of image/video analysis for real-time monitoring.	`ppe_detection`
	NLP	Analysis of unstructured text from safety reports.	`incident_trend_analysis`
CPMAI Framework	Business Understanding	Aligning AI project goals with HSE strategy.	`strategic_alignment`
	Data Management	Processes for data collection, cleaning, and preparation.	`data_quality`

	Model Lifecycle	The stages of model development, evaluation, and deployment.	`model_validation`
HSE Outcomes	Proactive Mitigation	Shifting from reactive to predictive safety interventions.	`proactive_safety`
	Decision Support	Providing data-driven insights to safety managers.	`decision_support`
	Safety Culture	Impact of AI on worker engagement and safety attitudes.	`culture_impact`
Theoretical Foundations	Socio-Technical Fit	The interplay between AI systems and human/organizational factors.	`socio_technical_fit`
	User Acceptance	Factors influencing the adoption of AI safety tools by workers.	`user_acceptance`
Implementation Strategy	Governance & Ethics	Policies for data privacy, fairness, and accountability.	`ai_governance`
	Skills & Training	The need to upskill the workforce for AI adoption.	`workforce_training`