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## **Integration of Lean Six Sigma and IOT-Based Real-Time Monitoring for Workplace Hazard Reduction in Industrial Facilities**

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**Doi:** [10.63125/xmhyhj07](https://doi.org/10.63125/xmhyhj07)

**Received:** 11 September 2024; **Revised:** 18 October 2024; **Accepted:** 20 November 2024; **Published:** 28 December 2024

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### **Abstract**

*This study examined the integration of Lean Six Sigma and IoT-based real-time monitoring for workplace hazard reduction in industrial and enterprise facility cases, addressing the persistent problem that conventional safety systems often depend on periodic inspections, manual reporting, and reactive corrective action, which may delay hazard detection and control. The purpose of the study was to determine whether structured process-improvement practices and real-time digital monitoring jointly improve hazard reduction outcomes in industrial facilities. A quantitative, cross-sectional, case-based research design was applied using primary questionnaire data collected from managers, supervisors, engineers, safety officers, technicians, and operational staff across selected enterprise/industrial cases. Out of 320 distributed questionnaires, 286 valid responses were analyzed, producing an effective response rate of 89.4%. The key variables were Lean Six Sigma implementation, IoT-based real-time monitoring, and workplace hazard reduction. The analysis plan included descriptive statistics, reliability testing, Pearson correlation, multiple regression, and interaction-effect testing. Findings showed that Lean Six Sigma recorded a positive grand mean of 3.91, IoT-based monitoring recorded a stronger mean of 4.08, and workplace hazard reduction recorded a mean of 4.02. Reliability was strong, with Cronbach's Alpha values of 0.87 for Lean Six Sigma, 0.89 for IoT monitoring, 0.85 for hazard reduction, and 0.87 for the full instrument. Correlation results showed significant positive relationships between Lean Six Sigma and hazard reduction,  $r = 0.61$ ,  $p < .01$ , and between IoT monitoring and hazard reduction,  $r = 0.68$ ,  $p < .01$ . Regression findings confirmed that Lean Six Sigma,  $\beta = 0.29$ ,  $p < .001$ , IoT monitoring,  $\beta = 0.37$ ,  $p < .001$ , and their interaction,  $\beta = 0.18$ ,  $p = .004$ , significantly predicted hazard reduction, explaining 44.2% of variance,  $R^2 = 0.442$ . The study implies that enterprise safety performance improves most when process discipline, sensor-based visibility, real-time alerts, and corrective-action systems operate as one integrated socio-technical framework.*

### **Keywords**

*Lean Six Sigma; IoT-Based Real-Time Monitoring; Workplace Hazard Reduction; Industrial Safety; Socio-Technical Systems.*

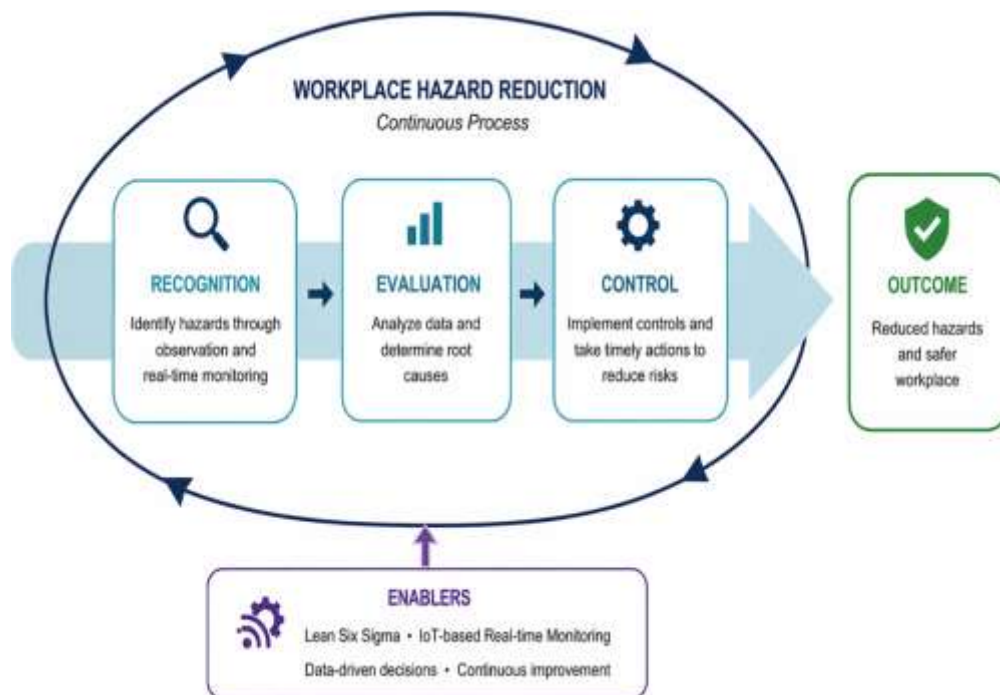
## **INTRODUCTION**

Workplace hazard reduction refers to the systematic identification, assessment, control, and continuous minimization of conditions that can cause injury, illness, process loss, or operational instability in work environments. In industrial facilities, hazards are commonly understood as physical, chemical, mechanical, electrical, ergonomic, and organizational exposures that arise from the interaction of workers, machines, materials, methods, and environments (Albliwi et al., 2014). Occupational safety scholarship has consistently framed hazard reduction as more than regulatory compliance because it is embedded in organizational climate, work design, supervision, and daily operating routines. Safety climate has been described as a multilevel organizational property that shapes how workers interpret management priorities and translate those priorities into safe or unsafe conduct. A broad body of evidence has also shown that safety climate is reliably associated with safety performance, while accident outcomes are influenced through safety motivation and safety behavior (Furman, 2019). Later studies reinforced the view that hazard outcomes are shaped by layered managerial and behavioral mechanisms rather than by isolated rules alone. Links have been established between psychological climate, work attitudes, and individual safety outcomes, while safety management practices have been shown to influence safety behavior through safety knowledge and motivation. In manufacturing settings, safety climate, leadership, workload, and accident experience have also been connected with workers' risk perception, and meta-analytic evidence has confirmed that safety climate retains predictive validity across industries, including high-risk sectors (Neal & Griffin, 2006). Taken together, these studies establish that workplace hazard reduction is an organizational and operational construct with international significance because industrial accidents interrupt productivity, damage equipment, weaken worker well-being, undermine quality performance, and increase the social and economic costs borne by firms and national labor systems. Within this broad field, the present topic is anchored in a management and technology perspective that views hazard reduction as a measurable outcome of structured process control, informed decision-making, and timely operational response rather than as an outcome generated only by periodic inspection or isolated safety campaigns (Clarke, 2006).

Lean, Six Sigma, and Lean Six Sigma are central concepts for understanding how industrial organizations redesign work to reduce error-producing conditions. Lean production is generally defined as a socio-operational system that seeks to maximize customer value while minimizing waste across processes, flows, inventories, waiting times, defects, and unnecessary motion (Clarke, 2010). One of the most influential operational definitions of lean production identifies interrelated bundles such as supplier feedback, just-in-time delivery, customer involvement, pull systems, flow orientation, and employee involvement. Six Sigma, by contrast, is usually framed as a disciplined and data-driven methodology for reducing process variation and improving quality through statistical analysis, structured problem solving, and defect control. It has been emphasized as a business improvement strategy that can be adapted across functions through project-based analysis, customer focus, and measurement discipline (Kale et al., 2022). The combined approach known as Lean Six Sigma integrates the waste-elimination logic of lean with the variation-reduction logic of Six Sigma. This integration has been described as an evolutionary movement toward a more comprehensive improvement architecture, and also as a continuous learning and improvement system that links strategy, measurement, process analysis, and execution. Subsequent reviews have deepened this understanding by showing that Lean Six Sigma is not a single tool but a managerial infrastructure involving DMAIC logic, process mapping, root-cause analysis, visual control, standardization, corrective action, and cross-functional learning (Koukoulaki, 2014). Critical failure factors such as weak leadership and poor cultural alignment have been catalogued in the literature, while broader methodological reviews have confirmed the maturity of Lean Six Sigma as an integrated performance-improvement approach. These definitions matter internationally because industrial facilities operate under pressure to improve productivity, product quality, compliance, and worker protection simultaneously. Lean Six Sigma is therefore relevant to workplace hazard reduction when unsafe conditions are interpreted as process defects, uncontrolled variability, procedural nonconformities, or signals of weak operational discipline embedded in the production system itself (Snee, 2010).

The relationship between Lean Six Sigma and occupational safety becomes especially important when industrial hazards are examined as outcomes of process instability, disorganized workstations, delayed maintenance, poor housekeeping, weak standard operating procedures, and incomplete root-cause learning. This line of thinking places safety within the same analytical field as quality and process capability. Evidence from ergonomics and occupational safety research has shown that lean production influences musculoskeletal and psychosocial risk through work intensification, workflow redesign, and managerial control mechanisms, making safety effects inseparable from the way lean is implemented. This insight is important because lean-oriented systems can alter work pace, task sequencing, and human-machine interaction (Hamja et al., 2019). At the same time, the literature has also documented that structured lean practices can strengthen safety when implementation includes ergonomic attention, standardized work, visual management, and continuous correction of unsafe conditions. The integration of occupational health and safety into lean manufacturing has therefore received explicit attention in industrial case studies, and empirical work has shown that work design and organizational implementation patterns shape whether lean-related changes support or weaken safety conditions. More operationally focused studies have further shown that specific lean tools may support safer environments by improving order, process transparency, and control. Selected lean management tools have been evaluated for their impact on work safety, while the effect of lean tools on safety levels in manufacturing organizations has also been examined directly (Hofmann & Rüsçh, 2017). Additional research has explored the alignment of lean practices with worker health and safety in manufacturing industries, and occupational health and safety management system frameworks have been proposed for lean process industries to formalize the relationship between lean process structures and safety governance. Within this body of literature, Lean Six Sigma can be read as a hazard-reduction logic because it turns recurring safety problems into analyzable process phenomena, encourages evidence-based corrective action, and treats unsafe variation as a controllable feature of system design and operational management (Svertoka et al., 2021).

**Figure 1: Workplace Hazard Reduction through Lean Six Sigma and IoT-Based Real-Time Monitoring**



IoT-based real-time monitoring adds a technological layer to industrial safety by enabling continuous data generation, communication, and response across connected production environments. The Internet of Things in industry is commonly defined as a network of identifiable physical objects

equipped with sensors, actuators, software, and connectivity that allows them to collect, exchange, and act upon data within operational systems. Industrial IoT has been described as a foundational architecture for connecting machines, devices, and processes in industrial settings, while Industry 4.0 research has linked digitally integrated logistics and production environments with visibility, interoperability, and data-rich decision support (Patel & Patel, 2021). The industrial internet of things has also been framed as an analytical and organizational architecture rather than simply a hardware upgrade, with emphasis placed on the interaction of devices, networks, applications, and governance. From a cyber-physical systems perspective, IIoT environments enable real-time awareness by synchronizing physical operations with digital representations, thereby supporting monitoring, automation, and feedback loops. In safety management terms, real-time monitoring refers to the continuous observation of variables such as temperature, vibration, gas concentration, machine state, worker location, posture, environmental exposure, and process deviations at or near the moment they occur (Ulewicz & Lazar, 2019). This capability changes the information conditions under which hazards are managed. Instead of relying exclusively on retrospective reports or periodic audits, industrial managers can access ongoing signals that reveal abnormal states before they escalate into injuries or incidents. International significance emerges here because industrial facilities across sectors face comparable demands for process continuity, worker protection, traceability, and regulatory accountability. As industrial operations become more interconnected, the quality of monitoring data shapes the timeliness of safety interventions and the precision of risk control. In that sense, IoT-based monitoring is not merely a technological convenience; it is a structural mechanism for converting dispersed workplace conditions into actionable operational knowledge that can be integrated with management systems, improvement routines, and daily supervision (Vinodkumar & Bhasi, 2010).

Within occupational safety research, the value of IoT-based real-time monitoring is strongest when it is connected to risk detection, situational awareness, and rapid intervention in complex industrial settings. Modern industrial hazards often evolve through short chains of events in which machine anomalies, environmental shifts, human fatigue, or unsafe movement patterns emerge before a visible accident occurs. Real-time monitoring technologies allow such precursor signals to be captured continuously. Connected wearable systems are increasingly used to monitor worker location, physiological state, posture, and environmental exposure, thereby strengthening the data infrastructure for hazard awareness at the worker level. Industry 4.0 research has also emphasized that digital technologies can reshape prevention by increasing information quality, traceability, and responsiveness inside production systems (Pepper & Spedding, 2010). This logic has been extended through real-time occupational safety monitoring studies in high-risk environments where industrial IoT and unsupervised deep learning have been used to support immediate safety observation. Although this kind of work is technologically specific, its broader relevance lies in demonstrating that real-time safety monitoring can move hazard management closer to the operational moment in which risk develops. Safety research on perception and behavior also supports the relevance of such systems. Workers' risk perception has been shown to be associated with safety climate, safety leadership, workload, and accident experience, indicating that workers interpret and respond to risks within informational and organizational contexts (Oah et al., 2018). Real-time monitoring contributes to that context by making hazards more visible, deviations easier to interpret, and unsafe conditions faster to escalate to supervisory action. In industrial facilities where a large share of hazards is process-linked, data-linked, or time-sensitive, the capacity to observe, alert, and document continuously becomes a practical extension of safety management rather than a separate technological domain. That framing is essential for a study on workplace hazard reduction because it places IoT not at the margin of industrial safety, but inside the daily operating logic through which risks are recognized and controlled (Xu et al., 2018).

A stronger analytical basis for the present research emerges when Lean Six Sigma and IoT-based real-time monitoring are considered together rather than as parallel but disconnected interventions. Lean Six Sigma supplies a structured language for problem definition, measurement, root-cause analysis, process control, and standardization, while IoT supplies continuous, granular, and time-sensitive operational data that can sharpen those same activities. Lean Six Sigma has been characterized as a learning-oriented improvement system and as an integrated methodology for process excellence. Later

reviews have confirmed that the methodology's enduring strength lies in its capacity to combine managerial discipline with evidence-based problem solving. In digitalized industrial environments, that evidence base can be significantly enriched by IIoT infrastructures that expose process deviations as they occur. Industrial IoT systems are particularly valuable when they support visibility, connectivity, and responsive control within cyber-physical production networks. From a safety standpoint, the integration becomes meaningful because hazard reduction requires both analytical discipline and timely data. Without structured improvement logic, real-time signals can remain underused; without continuous data, improvement routines may rely too heavily on lagging indicators and episodic reporting (Sakouhi & Nadeau, 2016). This connection has also been reinforced in occupational health and safety management system frameworks developed for lean process industries, where safety governance is linked directly to systemic process design. Related digital safety studies have further illustrated how technologically enabled monitoring can strengthen real-time safety management in environments where operational conditions change quickly (Zohar & Luria, 2005; Zorzenon et al., 2022). The conceptual value of integration is therefore grounded in complementarity: Lean Six Sigma organizes how problems are interpreted and corrected, while IoT-based monitoring strengthens how problems are observed, measured, and escalated. In industrial facilities, where hazards often arise from process variation, equipment conditions, environmental exposure, and human-system interaction, this combined architecture provides a coherent frame for understanding hazard reduction as the result of synchronized managerial and technological control rather than as the outcome of isolated safety practices or fragmented digital deployment (Singh et al., 2021).

The scholarly basis for this research is further strengthened by the fact that existing studies offer substantial insight into workplace safety climate, Lean Six Sigma methodology, lean-related health and safety conditions, and digital monitoring technologies, yet the integrated quantitative examination of Lean Six Sigma and IoT-based real-time monitoring for workplace hazard reduction in industrial facilities remains comparatively underdeveloped (Shah & Ward, 2007). Safety research has shown how climate, motivation, knowledge, and work design relate to injury prevention and risk behavior. Lean and Lean Six Sigma studies have established the methodological foundations for structured process improvement and have also explored safety-related effects within manufacturing and process industries (Antony, 2006; Boyes et al., 2018). The digital literature has clarified the architectures, capabilities, and monitoring potential of IIoT environments, including wearable and real-time safety applications. What emerges from this body of knowledge is a strong foundation for studying workplace hazard reduction as a measurable industrial outcome shaped by process discipline and data visibility at the same time. The topic is also internationally significant because industrial facilities continue to manage tightly coupled systems in which quality, productivity, and worker safety are operationally interconnected rather than isolated domains (Xu et al., 2014). A research design that focuses on quantitative, cross-sectional, case-study-based evidence is well aligned with this context because it allows the relationships among Lean Six Sigma implementation, IoT-based real-time monitoring, and workplace hazard reduction to be examined through descriptive statistics, correlation analysis, and regression modeling using worker and managerial assessments from actual industrial settings (Zhan et al., 2022). Such an approach situates the introduction within a literature stream that defines key concepts clearly, anchors them in internationally relevant industrial realities, and establishes the empirical space in which integrated safety-oriented process management can be studied rigorously (Jiang et al., 2019).

### **Background of the Study**

The background of this study is rooted in the growing need for safer and smarter industrial workplaces where hazard prevention is treated as a continuous operational priority rather than a periodic compliance task. Industrial facilities such as manufacturing plants, processing units, warehouses, and heavy engineering environments are often exposed to multiple workplace hazards that emerge from machinery movement, unsafe process conditions, equipment failure, environmental exposure, human error, poor housekeeping, and weak monitoring systems. As industrial operations become more complex, interconnected, and time-sensitive, conventional safety management approaches that rely mainly on manual inspection, paper-based reporting, and delayed corrective action are increasingly limited in their ability to detect and control hazards at the moment they develop. At the same time,

organizations are under constant pressure to improve productivity, maintain quality, reduce waste, protect employees, and sustain uninterrupted operations. This situation has created a strong need for management systems that can integrate operational efficiency with workplace safety in a measurable and responsive way. Lean Six Sigma has emerged as an important improvement approach because it helps organizations reduce process variation, eliminate non-value-adding activities, standardize procedures, identify root causes of recurring problems, and build a culture of continuous improvement. In industrial settings, many safety incidents are closely connected to process instability, lack of standardization, delayed maintenance, and weak control of workplace conditions, which makes Lean Six Sigma highly relevant to hazard reduction. In parallel, the rise of IoT-based real-time monitoring has transformed the way industrial environments can be observed and managed. Through sensors, connected devices, real-time alerts, dashboards, and automated tracking systems, organizations can monitor equipment status, environmental changes, worker movement, and abnormal operating conditions as they occur. This real-time visibility strengthens the speed and accuracy of hazard identification and supports faster intervention before risks escalate into injuries or operational losses. The integration of Lean Six Sigma with IoT-based real-time monitoring therefore represents a practical and timely response to modern industrial safety challenges. It combines process discipline with live operational intelligence, creating a stronger foundation for proactive hazard control. This study is based on the understanding that workplace hazard reduction can be improved when structured continuous improvement methods are supported by real-time technological monitoring within industrial facilities.

### **Problem Statement**

Industrial facilities continue to experience workplace hazards even though many organizations have already adopted formal safety rules, inspection routines, and compliance-based risk management procedures. In many cases, the persistence of accidents, near misses, unsafe acts, and hazardous process conditions suggests that traditional approaches to safety management are not sufficiently responsive to the dynamic and interconnected nature of modern industrial operations. Hazards in industrial environments often emerge from a combination of process inefficiency, equipment malfunction, human error, poor communication, delayed maintenance, environmental instability, and limited visibility into real-time operating conditions. When safety management depends largely on periodic inspections, manual reporting, or post-incident investigation, organizations may identify problems only after damage, disruption, or injury has already occurred. This creates a major operational gap between hazard emergence and hazard control. At the same time, Lean Six Sigma has been widely recognized as a structured method for reducing process variation, eliminating waste, standardizing workflows, and improving operational discipline, while IoT-based real-time monitoring has introduced new possibilities for continuous observation, early warning, and immediate response to abnormal workplace conditions. Even so, these two approaches are often implemented separately, with Lean Six Sigma focused on productivity and quality improvement, and IoT systems focused on technological tracking without being fully embedded in a broader improvement strategy. As a result, industrial organizations may fail to capture the full safety value that could emerge from integrating process-based continuous improvement with real-time monitoring technologies. The central problem addressed by this research is that there remains insufficient quantitative evidence on how the integration of Lean Six Sigma and IoT-based real-time monitoring influences workplace hazard reduction in industrial facilities. More specifically, it is unclear to what extent Lean Six Sigma contributes to hazard reduction, how strongly IoT-based monitoring improves workplace safety performance, and whether their combined implementation produces a more effective hazard-control system than isolated use of either approach. This problem is important because industrial organizations require practical and measurable strategies for minimizing hazards while maintaining efficient and uninterrupted operations. Therefore, this study seeks to address a clear knowledge and practice gap by examining the relationship between Lean Six Sigma, IoT-based real-time monitoring, and workplace hazard reduction within an industrial context.

### **Objectives of The Study**

The objective of this study is to examine the extent to which the integration of Lean Six Sigma and IoT-based real-time monitoring contributes to workplace hazard reduction in industrial facilities. This

broad objective is built on the understanding that hazard reduction in industrial environments requires more than routine compliance measures and isolated safety inspections; it requires a coordinated system that improves process discipline while also increasing visibility into real-time operational conditions. Specifically, the study seeks to assess the role of Lean Six Sigma as a structured management approach that can reduce unsafe variability, improve standardization, strengthen root-cause problem solving, and support continuous improvement in safety-related processes. In addition, the study aims to evaluate the contribution of IoT-based real-time monitoring by examining how sensor-enabled tracking, real-time alerts, connected devices, and ongoing data visibility may enhance early hazard identification, rapid response, and proactive workplace safety control. Another major objective is to determine the nature and strength of the relationship between Lean Six Sigma practices and workplace hazard reduction, as well as the relationship between IoT-based real-time monitoring and workplace hazard reduction. Beyond these separate effects, the study also aims to investigate the combined influence of Lean Six Sigma and IoT-based monitoring to understand whether an integrated framework provides a stronger and more effective mechanism for hazard reduction than the isolated implementation of process improvement methods or monitoring technologies alone. In practical terms, the study is designed to generate measurable evidence from respondents working in industrial settings so that the individual and joint contributions of these variables can be statistically examined through descriptive analysis, correlation, and regression modeling. By doing so, the research intends to move the discussion of workplace safety beyond general assumptions and toward evidence-based assessment of how industrial organizations can reduce hazards through the coordinated use of operational excellence methods and smart monitoring systems. The objective-based direction of this study therefore reflects a focused effort to produce empirical findings that explain how structured improvement practices and real-time technological oversight can work together to strengthen workplace safety performance in industrial facilities.

### **Research Hypotheses**

The research hypotheses of this study are developed to test the presumed relationships between Lean Six Sigma, IoT-based real-time monitoring, and workplace hazard reduction in industrial facilities. These hypotheses provide a clear and measurable framework through which the study can evaluate whether the independent variables have meaningful statistical associations and predictive effects on the dependent variable. Since Lean Six Sigma is designed to reduce variation, eliminate waste, improve standardization, and strengthen process control, it is expected that stronger implementation of Lean Six Sigma practices will be associated with lower levels of workplace hazards and improved safety outcomes. In the same way, IoT-based real-time monitoring is expected to contribute positively to workplace hazard reduction because it enables continuous observation, timely detection of unsafe conditions, faster reporting, and more immediate corrective action. The logic of the study also assumes that workplace hazard reduction is not influenced by these factors in isolation only, but that the integration of structured process improvement and real-time technological monitoring may produce a stronger combined effect. Based on this reasoning, the hypotheses are formulated to test both separate and joint relationships among the variables. The first hypothesis states that Lean Six Sigma implementation has a significant positive effect on workplace hazard reduction. The second hypothesis states that IoT-based real-time monitoring has a significant positive effect on workplace hazard reduction. The third hypothesis states that there is a significant positive relationship between Lean Six Sigma and workplace hazard reduction. The fourth hypothesis states that there is a significant positive relationship between IoT-based real-time monitoring and workplace hazard reduction. The fifth hypothesis states that the integration of Lean Six Sigma and IoT-based real-time monitoring significantly predicts workplace hazard reduction in industrial facilities. These hypotheses are important because they convert the study's conceptual assumptions into statistically testable statements. They also create a direct link between the theoretical orientation of the study and its quantitative methodology by allowing the researcher to use descriptive statistics, correlation analysis, and regression modeling to determine whether the expected relationships are supported by empirical data. In this way, the hypotheses provide the analytical foundation for validating the objectives of the study and for explaining the extent to which integrated managerial and technological practices can improve workplace safety in industrial settings.

### **Significance of the Research**

The significance of this research lies in its potential to contribute meaningful value to academic knowledge, industrial practice, safety management systems, and policy-related decision making regarding workplace hazard reduction in industrial facilities. The study is important because it examines the combined role of Lean Six Sigma and IoT-based real-time monitoring in a way that connects process improvement with smart safety technology, thereby addressing a practical and research-based need in contemporary industrial environments.

**i. Academic significance:** This study contributes to the body of knowledge on industrial safety, operational excellence, and technology-enabled risk management by examining how Lean Six Sigma and IoT-based real-time monitoring relate to workplace hazard reduction within a quantitative framework.

**ii. Theoretical significance:** The study strengthens conceptual understanding of how process discipline and real-time technological visibility can function together within an integrated safety-management perspective, thereby offering a clearer basis for interpreting workplace hazard reduction as both a managerial and technological outcome.

**iii. Methodological significance:** By applying a quantitative, cross-sectional, case-study-based design supported by descriptive statistics, correlation analysis, and regression modeling, the research offers a structured empirical approach for examining hazard reduction in industrial settings.

**iv. Practical significance for industrial managers:** The findings may help managers understand whether integrating Lean Six Sigma with IoT-based monitoring can support safer operations, better process control, and more effective hazard prevention within industrial facilities.

**v. Significance for safety officers and operational staff:** The study can provide useful insight into how real-time monitoring systems and continuous improvement practices can improve hazard detection, incident prevention, and workplace safety responsiveness on a day-to-day basis.

**vi. Technological significance:** This research highlights the practical value of IoT-based systems not merely as digital tools, but as active components of workplace hazard management that can enhance visibility, tracking, and early intervention in industrial environments.

**vii. Policy and organizational significance:** The study may support organizations and decision makers in designing stronger workplace safety strategies, investment priorities, and operational policies that combine structured process improvement with live technological monitoring to reduce risks more effectively.

### **LITERATURE REVIEW**

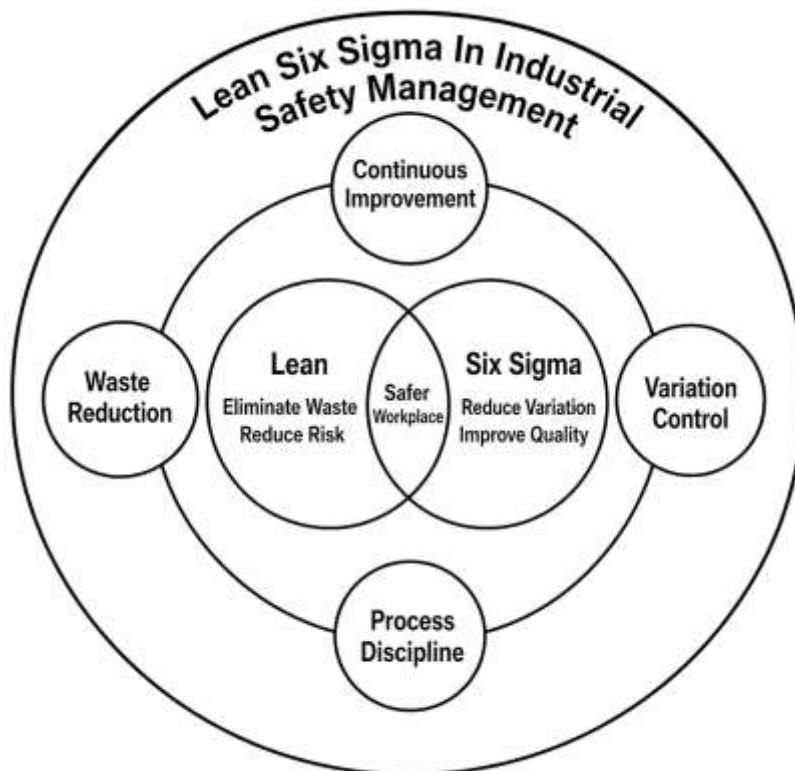
The literature review for this study provides the intellectual and empirical foundation for understanding how the integration of Lean Six Sigma and IoT-based real-time monitoring may influence workplace hazard reduction in industrial facilities. It is important to review the literature because the topic sits at the intersection of industrial safety management, process improvement, digital monitoring systems, and organizational performance. Workplace hazards in industrial environments are shaped by multiple interacting factors, including process instability, unsafe operating conditions, equipment failure, environmental exposure, weak reporting systems, inconsistent procedures, and human error. For this reason, the literature must be approached from a broad but interconnected perspective that captures both managerial and technological dimensions of hazard control. On the managerial side, Lean Six Sigma provides an important body of knowledge on waste elimination, reduction of process variation, standardization, root-cause analysis, and continuous improvement, all of which are relevant to workplace safety when unsafe conditions are treated as process failures or controllable operational defects. On the technological side, IoT-based real-time monitoring offers a growing field of knowledge centered on sensors, connected devices, live dashboards, automated alerts, and real-time visibility into industrial conditions, which are increasingly important for identifying hazards quickly and enabling timely intervention. The literature review is therefore expected to clarify how these two domains have evolved, how they relate to workplace hazard reduction, and where major research gaps remain. It also serves to identify the theoretical perspective that will guide the study and the conceptual structure through which the variables are linked. In addition, the literature review helps position the present study within previous empirical work by examining what has already been discovered about industrial safety, Lean Six Sigma applications, digital monitoring systems, and

integrated safety-performance strategies. By synthesizing relevant knowledge in a structured way, the literature review establishes the scholarly basis for the research problem, justifies the study objectives and hypotheses, and creates a coherent framework for interpreting the findings. In this sense, the literature review is not only a summary of previous studies, but a critical foundation that shapes the overall direction, logic, and academic strength of the research.

### **Lean Six Sigma in Industrial Safety Management**

Lean Six Sigma in industrial safety management can be understood as the application of continuous improvement logic, defect reduction principles, and process discipline to the prevention of workplace hazards and the stabilization of operating conditions. In industrial facilities, unsafe acts and unsafe conditions rarely appear as isolated events; they are usually linked to process delays, disorganized material flow, poor workstation arrangement, excessive motion, rework, maintenance weaknesses, communication gaps, and nonstandard task execution. For that reason, Lean Six Sigma is highly relevant to workplace safety because it treats operational problems as measurable process failures that can be defined, analyzed, controlled, and systematically reduced. Lean contributes by identifying non-value-adding activities, improving workplace organization, simplifying flows, and reducing operational clutter that may expose workers to unnecessary risk. Six Sigma contributes by reducing variation, strengthening root-cause analysis, improving measurement discipline, and promoting evidence-based corrective action. When merged, the two approaches form a management philosophy that is not limited to productivity and quality alone, but that also supports safer work through better process visibility and stronger control of deviations. Early lean scholarship in the process industries emphasized that lean thinking is especially valuable when organizations seek to shorten lead times, simplify workflows, remove waste, and improve operational responsiveness, all of which indirectly support safer and more predictable working conditions.

**Figure 2: Lean Six Sigma Framework for Industrial Safety Management**



Later safety-oriented reviews extended this logic by showing that lean implementation affects the working environment through job design, participation, standardization, and operational intensity, meaning that the quality of implementation determines whether lean becomes a source of control or a source of strain. In this sense, Lean Six Sigma in safety management should be viewed not merely as a

set of tools, but as a structured system for redesigning work so that hazards are less likely to be generated by the production process itself (Hasle et al., 2012; Istiaq & Binte, 2023). A more detailed understanding of Lean Six Sigma in industrial safety management emerges when attention is given to ergonomics, worker interaction with the production system, and the human consequences of poorly designed lean implementation. Industrial safety is not achieved only by removing defects from products or delays from workflows; it also depends on whether the redesigned system reduces biomechanical stress, cognitive overload, excessive pace, and unsafe exposure at the point where workers engage with machines, tools, and materials. This is why the ergonomic dimension of Lean Six Sigma is particularly important (Nunes, 2015; Binte & Sazzadul, 2022). A safety-oriented lean environment must support standardized work without creating rigid overload, visual management without causing informational clutter, and process flow without intensifying fatigue or reducing recovery opportunities. Literature in this area has shown that lean production environments influence work pace, load, worker motivation, participation, and health outcomes, indicating that safety performance is closely connected to how improvement initiatives reshape the real experience of work on the shop floor. From this perspective, Lean Six Sigma becomes stronger when it is aligned with ergonomics because continuous improvement then addresses not only output efficiency but also the conditions under which that output is produced. This alignment is especially important in industrial facilities where repetitive tasks, manual handling, constrained spaces, and time-sensitive processes can convert small design flaws into recurring safety problems. A systems-oriented model that integrates ergonomics with Lean Six Sigma has therefore been proposed to ensure that gains in productivity are accompanied by gains in working conditions, suggesting that effective improvement requires simultaneous attention to process capability and human capability. For the present study, this insight is central because workplace hazard reduction cannot be separated from the way tasks are structured, monitored, and physically performed inside industrial operations (Arezes et al., 2015).

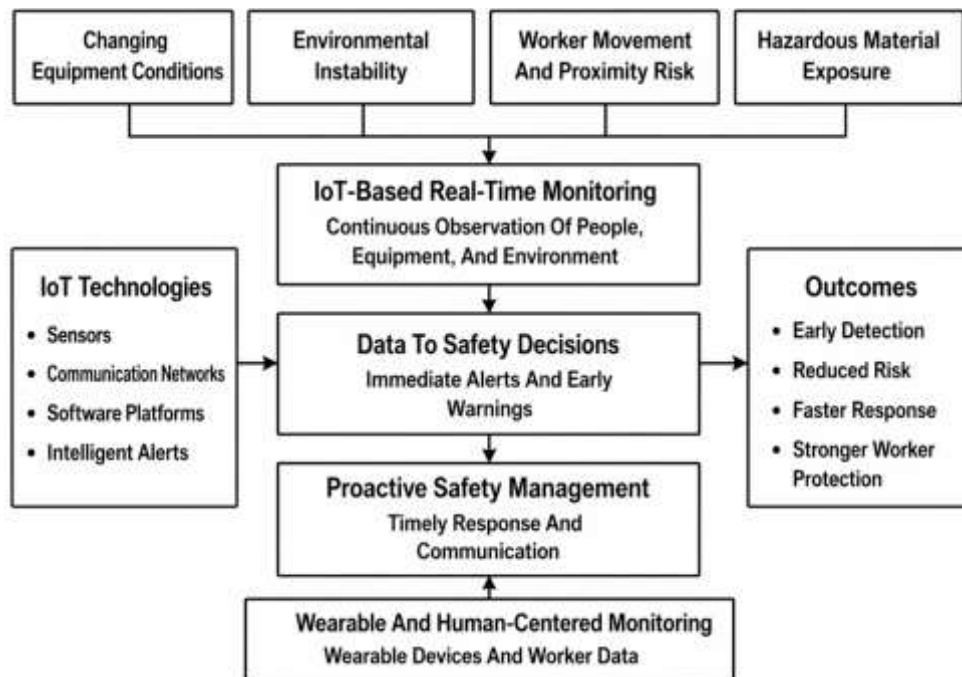
The industrial safety value of Lean Six Sigma becomes even clearer when the methodology is interpreted as a disciplined mechanism for turning accident patterns, unsafe behaviors, and hazardous process conditions into analyzable improvement projects. Safety management in many industrial organizations has traditionally relied on inspections, incident reporting, and compliance audits, which are important but often reactive. Lean Six Sigma adds a different layer of control by forcing organizations to define the safety problem clearly, measure the extent of exposure or failure, analyze root causes systematically, implement targeted improvements, and sustain control over the revised process (Islam & Aditya, 2023; Melton, 2005). This DMAIC logic is highly compatible with workplace hazard reduction because many safety issues involve recurrent losses that can be tracked statistically and corrected operationally. In practical terms, a Lean Six Sigma view of safety would address issues such as disorder in material placement, repeated manual handling errors, inconsistent use of personal protective systems, delayed maintenance response, and accident clusters around particular workstations or process stages. Such an approach strengthens industrial safety management by shifting attention from isolated blame toward process-centered diagnosis and controlled improvement. Recent case evidence from the automotive branch has demonstrated that the DMAIC cycle can be directly applied to workplace safety improvement through the use of structured tools such as Pareto analysis, matrix diagrams, cause-and-effect analysis, verification of causes, and control charts, showing that Six Sigma methods can reduce accident-related costs and improve safety performance when adapted to occupational risk contexts. This application is particularly relevant for the present research because it supports the argument that Lean Six Sigma offers not only a theoretical connection to safety, but also an operational pathway through which industrial facilities can translate continuous improvement into measurable hazard reduction. Accordingly, Lean Six Sigma in industrial safety management is best understood as a practical architecture for embedding prevention, standardization, and sustained control into the everyday design of industrial work (Knop, 2022; Khaled, 2021).

### **IoT-Based Real-Time Monitoring in Industrial Facilities**

IoT-based real-time monitoring in industrial facilities refers to the use of interconnected sensors, identification technologies, communication networks, software platforms, and intelligent alert mechanisms to observe workplace conditions continuously and convert live operational data into safety-related decisions. In industrial environments, hazards often emerge from changing equipment

states, environmental instability, hazardous material exposure, worker movement, spatial conflicts, and delayed recognition of abnormal process conditions. Real-time monitoring becomes important because these hazards develop dynamically rather than remaining fixed or easily predictable through routine inspection alone. The literature shows that IoT-based systems are increasingly designed to reduce this visibility gap by linking physical objects and operating environments to digital platforms that can detect, communicate, and respond to unsafe situations as they occur. A particularly important contribution to this field is the development of system-level safety architectures that do not treat monitoring as a standalone device function, but as an integrated safety-management process. For example, an intelligent safety-management prototype for the process industry demonstrated how smart objects, digital platforms, localization tools, and maintenance-related data can be combined to manage hazards involving both plants and workers in a single operational environment (Gnoni et al., 2020). This kind of architecture is highly relevant to industrial facilities because many safety threats are not limited to worker behavior alone; they also involve the condition of equipment, the timing of maintenance, and the interaction between physical assets and human presence. In that sense, IoT-based real-time monitoring improves safety by creating a continuous data stream about operational reality rather than relying only on delayed reporting, periodic auditing, or manual observation. The value of this approach is especially strong in complex facilities where hazards can escalate quickly and where safety depends on immediate recognition of deviations. Therefore, IoT-based monitoring should be understood as a proactive safety infrastructure that strengthens observation, communication, traceability, and response within industrial systems, making hazard reduction more timely, measurable, and operationally grounded (Nazmul & Begum, 2022; Zhou & Ding, 2017).

**Figure 3: IoT-Based Real-Time Monitoring Framework For Industrial Safety**



A second important theme in the literature is that IoT-based real-time monitoring improves industrial safety by making worker exposure and proximity risk visible at the moment they occur. Many industrial accidents are linked to restricted-area intrusion, unsafe closeness to equipment, movement into danger zones, or inability to recognize hazards in fast-changing workspaces. IoT technologies address this challenge by using location sensors, radio-frequency systems, ultrasonic detection, and real-time communication to produce immediate alerts and guide worker behavior before an incident occurs. Research on underground construction environments, which share several characteristics with

other high-risk industrial settings such as confined spaces, changing hazards, heavy equipment interaction, and environmental uncertainty, has shown that IoT-based warning systems can isolate hazard energy in real time through digital barriers, early warnings, and automated monitoring of unsafe conditions (Zaheda, 2021; Zhou & Ding, 2017). Similarly, an IoT-based autonomous safety system developed for workers in construction sites demonstrated how real-time alarming, monitoring, and positioning strategies can be used to localize workers and warn them when they approach hazardous zones, showing that connected safety technologies can support both prevention and immediate intervention (Kanan et al., 2018). Another useful contribution comes from research on worker location-based safety performance indicators, where real-time sensor data were used to measure proximity events and transform them into leading indicators of individual safety performance (Manam & Ashfaq, 2022; Reis et al., 2020). Although some of these studies were conducted in construction-related settings, their conceptual value extends strongly to industrial facilities because factories, warehouses, process plants, and heavy engineering environments also involve moving equipment, hazard zones, restricted areas, and the need for continuous spatial awareness. The broader implication is that IoT-based monitoring enables organizations to move from static safety control to dynamic safety control. Instead of documenting incidents after exposure has already happened, firms can identify unsafe proximity, monitor worker-location patterns, and generate warning signals before injury occurs. This is a major shift in industrial safety logic because it turns live operational movement into actionable preventive information.

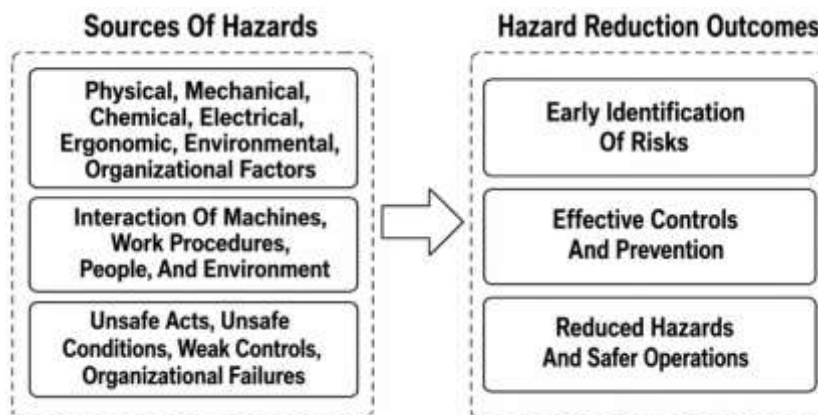
A third dimension of the literature shows that IoT-based real-time monitoring in industrial facilities is increasingly expanding from environmental and positional monitoring toward wearable, platform-based, and human-centered safety systems. This development is important because industrial hazards are not only external to the worker; they can also involve fatigue, stress, heat exposure, posture-related strain, and misuse or noncompliance regarding protective equipment. Wearable and smart personal protective systems extend IoT monitoring by integrating worker-related physiological or movement data with the surrounding environmental context, thereby creating a more responsive safety ecosystem. A literature review on wearable devices in production systems highlighted that Industry 4.0 has accelerated the adoption of smart watches, wristbands, IMU-based devices, and related wearables for monitoring stress, fatigue, movement, and other health-and-safety variables in production environments, indicating that worker-centered data are becoming increasingly important in modern safety management (Pasquale et al., 2022; Shahinur & Sultan, 2022). In a similar direction, an intelligent platform based on smart personal protective equipment showed how helmets, belts, bracelets, edge computing, and anomaly-detection methods can be combined to monitor workers and their environments in order to support early recognition of dangerous situations (Herrera-Santos, et al., 2021). These studies are especially relevant to industrial facilities because they demonstrate that real-time monitoring is no longer limited to fixed sensors attached to machines or spaces; it is evolving into a distributed network of connected safety devices that travel with the worker and interact with digital platforms continuously. This widens the practical scope of hazard reduction by supporting not only site-level observation but also individualized protection, faster communication, and more adaptive response. For the present research, the significance of this literature lies in showing that IoT-based real-time monitoring has matured into a broad safety capability that can strengthen visibility, reduce delayed detection, and support more precise intervention in industrial facilities. As a result, IoT monitoring provides a strong technological foundation for hazard reduction, especially when its real-time data are aligned with broader process-improvement and safety-management systems inside industrial organizations (Reis et al., 2020; Binte & Hasan Or, 2022).

### **Workplace Hazards and Hazard Reduction in Industrial Facilities**

Workplace hazards in industrial facilities refer to the broad range of physical, mechanical, electrical, chemical, ergonomic, environmental, and organizational conditions that can expose workers to injury, illness, or operational harm during the course of production activities. In manufacturing plants, warehouses, process industries, and heavy engineering settings, hazards are rarely limited to a single source; rather, they emerge from the interaction of machines, work procedures, layouts, human behavior, production pressure, supervision quality, and the surrounding work environment. This makes hazard reduction a complex management concern rather than a narrow compliance exercise. A

useful way to understand this issue is through accident causation research, which explains that occupational incidents are produced by multiple layers of contributing factors, including unsafe acts, unsafe conditions, weak controls, and broader organizational failures. In this view, workplace hazards should not be treated only as isolated events at the point of injury, but as indicators of deeper process and management weaknesses that require systematic prevention. Manufacturing-based evidence also shows that injury outcomes are shaped by how effectively firms implement safety and health practices in everyday operations. Where structured safety routines, training, and control mechanisms are weak, injury management becomes more difficult and hazard exposure tends to persist. Closely related evidence from studies of occupational health and safety management practices in companies further indicates that the quality of safety culture, organizational capacity, and management systems affects how well firms identify, assess, and control risks across the workplace. This means that workplace hazard reduction in industrial facilities is inseparable from the strength of the organizational systems that govern daily work. Hazard reduction therefore involves more than responding to accidents after they occur; it requires a preventive system that can detect risk sources early, organize controls effectively, and maintain safe performance over time. For the present research, this understanding is important because it frames workplace hazard reduction as a measurable outcome of industrial management quality and operational control rather than as an incidental by-product of regulation alone (Cornelissen et al., 2017; Nordlöf et al., 2017).

**Figure 4: Workplace Hazards And Hazard Reduction Outcomes In Industrial Facilities**



A second key issue in the literature is that hazard reduction depends on recognizing both the visible and the less visible conditions that make industrial accidents possible. Some hazards are obvious, such as moving machinery, sharp tools, exposed electrical components, high temperatures, hazardous substances, slippery floors, and confined spaces. Others are embedded in work organization, such as fatigue, production pressure, poor communication, weak supervision, inadequate maintenance, and insufficient learning from previous incidents. Studies that review safety outcomes across high-risk industries show that accident prevention is strongly shaped by management and colleague influences, work-place characteristics and circumstances, climate and culture, and employee-related factors. This suggests that workplace hazards are not only technical problems but also behavioral and organizational problems. The literature on accident causation reinforces this position by arguing that organizations need to understand how accidents are produced if they want to prevent them effectively. Hazard reduction therefore requires a move from reactive thinking toward a more analytical and preventive approach in which hazards are identified, categorized, and addressed before they escalate into injuries. This is why occupational health and safety management systems are so central in industrial contexts: they create the procedural structure through which firms inspect conditions, document risks, assign responsibilities, and follow through on corrective measures. Even within manufacturing settings, companies vary considerably in how effective these systems are, and those differences influence the quality of hazard control in practice. Similarly, safety and health practices in manufacturing have been shown to be positively associated with injury management, indicating that stronger day-to-day safety

structures help organizations deal with workplace risks more effectively. In practical terms, hazard reduction in industrial facilities involves reducing the frequency and severity of unsafe exposure, minimizing process conditions that allow hazards to recur, and building stronger organizational responsiveness to warning signals. This perspective is highly relevant to the present study because it supports the idea that hazard reduction should be examined as an operational outcome shaped by the quality of industrial systems, not simply as a record of injuries after the fact (Dyreborg et al., 2022; Md, 2023).

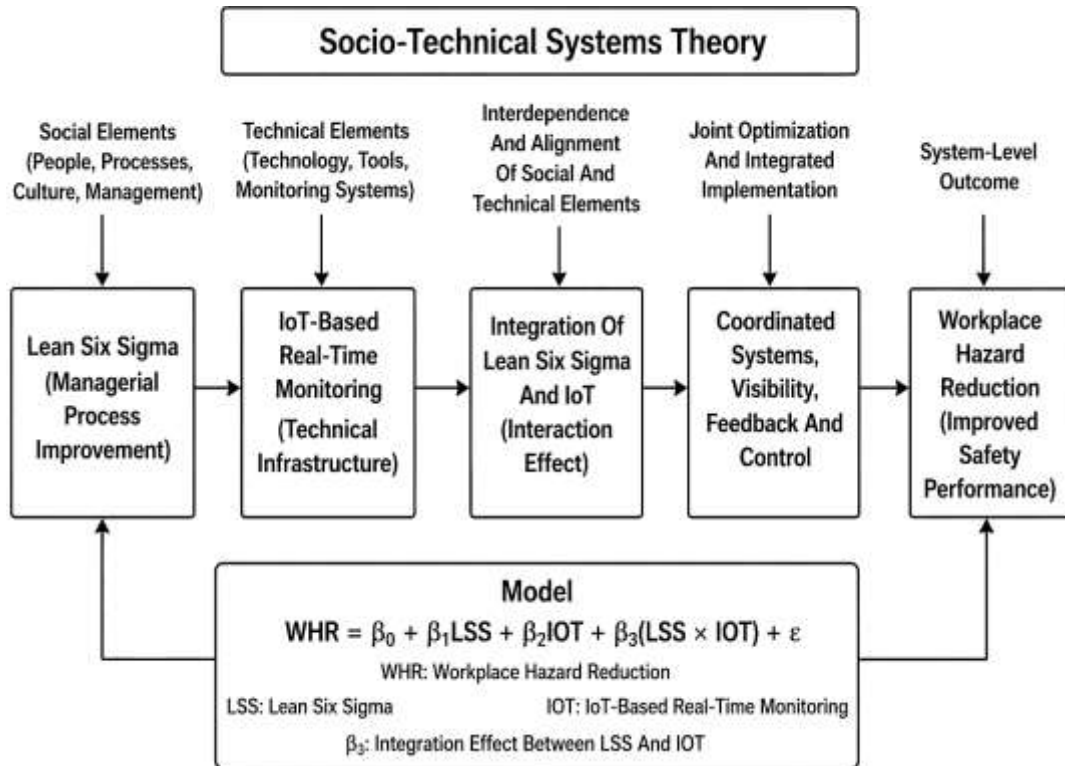
A third theme in the literature is that effective hazard reduction requires interventions that are systematic, sustained, and focused on controlling risks at their source. Industrial hazards cannot be reduced consistently through awareness campaigns or procedural statements alone if the underlying conditions that produce exposure remain unchanged. Evidence from systematic reviews of workplace safety interventions shows that accident prevention is more effective when interventions strengthen the work environment, tools, machines, and working conditions rather than relying only on workers to compensate for hazards individually. This is especially relevant in industrial facilities where exposure often develops through routine tasks, repetitive operations, high-speed processes, and interactions with heavy equipment. The literature also suggests that organizations benefit from learning not only from accidents, but from the warning signs that precede them. Research on accident causation and broader safety management argues that prevention improves when companies pay attention to precursor conditions and treat them as opportunities for organizational learning. In practical industrial settings, this means that near misses, unsafe conditions, weak housekeeping, procedural deviations, and recurrent minor failures should be used as diagnostic signals for future hazard reduction. At a broader level, workplace hazard reduction can therefore be understood as a process of continuously improving the fit between people, procedures, equipment, and environment so that accidents become less likely and safer performance becomes more stable. This interpretation aligns closely with the goals of the present study because it highlights that hazard reduction is not only about decreasing injury rates; it is also about improving the systems that prevent hazardous conditions from being created, overlooked, or repeated inside industrial facilities. When hazard reduction is framed in this way, it becomes possible to examine how structured management methods and technological monitoring tools may strengthen one another in building safer industrial operations. Thus, the literature on workplace hazards and hazard reduction provides a strong basis for studying industrial safety as a measurable outcome of prevention quality, organizational discipline, and effective intervention design (Pillay, 2015; Taufek et al., 2016).

### **Theoretical Framework: Socio-Technical Systems Theory**

Socio-Technical Systems Theory provides the most suitable theoretical foundation for this study because it explains organizational performance as the outcome of interdependence between social elements and technical elements within a work system. In industrial facilities, safety is not produced by machines alone, workers alone, or management rules alone; it emerges from the way people, technologies, workflows, supervision systems, communication patterns, and environmental conditions interact during daily operations. A socio-technical perspective is therefore especially relevant to workplace hazard reduction because industrial hazards usually arise when there is poor alignment between human activity and technical infrastructure. The theory moves analysis beyond narrow accident explanations that focus only on worker error or equipment failure and instead encourages the researcher to examine the whole work system as a coordinated but potentially unstable arrangement of tasks, controls, tools, procedures, and organizational influences. In workplace safety scholarship, this perspective has been strongly advanced through conceptual work arguing that meaningful safety improvement requires a shift from the individual worker as the sole unit of analysis toward the broader sociotechnical system in which workers operate. Workplace safety framework that places the local work system, socio-organizational context, and external environment in a layered relationship, showing that safe performance depends on how these levels interact rather than on isolated frontline behavior alone. Socio-technical approaches are valuable because they open new directions for analyzing sustainable and safe work systems while identifying research priorities that traditional safety models often overlook. Safe and unsafe work systems can be differentiated by examining sociotechnical attributes such as joint optimization, reliable human-system performance, realistic safety objectives,

and worker input into system design (Davies et al., 2017; Kleiner et al., 2015). Collectively, these contributions establish that workplace safety should be understood as an emergent property of the whole industrial system, which makes Socio-Technical Systems Theory highly appropriate for explaining how managerial approaches like Lean Six Sigma and technical infrastructures like IoT-based monitoring may jointly influence hazard reduction in industrial facilities (Carayon et al., 2015; Khaled & Hisham, 2022).

Figure 5: Socio-Technical Systems Theory Framework for Workplace Hazard Reduction



The relevance of Socio-Technical Systems Theory becomes even stronger when the present study is viewed in the context of digitalized industrial operations. Modern industrial facilities increasingly rely on cyber-physical production arrangements in which sensors, machines, software, dashboards, and operators are tied together in real time. Under such conditions, safety can no longer be explained adequately through a purely technical model of automation or a purely social model of worker behavior. Instead, the theory suggests that organizational outcomes improve when social and technical subsystems are jointly optimized. This principle fits the present research very closely because Lean Six Sigma represents a social-managerial mechanism of process discipline, standardization, and continuous improvement, while IoT-based real-time monitoring represents a technical mechanism of visibility, sensing, feedback, and rapid alerting. Davies et al. argued that the successful implementation of Industry 4.0 requires attention to socio-technical considerations rather than technical efficiency alone, because the value of connected technologies depends on internal capabilities, organizational readiness, and human integration. Sony and Naik extended this argument by explicitly linking Industry 4.0 integration with Socio-Technical Systems Theory and proposing that successful digital integration requires consideration of people, infrastructure, technology, processes, culture, and organizational goals as an interconnected system (Begum & Kaniz, 2023; Sony & Naik, 2020). These arguments are directly applicable to this study because workplace hazard reduction in industrial facilities depends on whether process-improvement routines and monitoring technologies are aligned in practice. A factory may install advanced sensors, but hazard control will remain weak if the organization lacks standardized procedures, root-cause analysis, responsive supervision, and

corrective-action discipline. Likewise, a plant may adopt Lean Six Sigma initiatives, but the speed and precision of hazard detection may remain limited if the organization lacks real-time technical feedback from connected devices and monitoring systems. Socio-Technical Systems Theory therefore provides a coherent explanation for why integration matters: safety performance improves when human, organizational, and technological elements are coordinated toward a common protective objective rather than managed as separate domains (Davis et al., 2014; Ashfaq & Manam, 2023).

For the present study, Socio-Technical Systems Theory is not only a descriptive framework but also an analytical guide for model specification. The theory supports the assumption that workplace hazard reduction is shaped by both social-managerial structures and technical-monitoring structures, and that the strongest safety outcomes are likely to appear when those structures reinforce each other. This logic justifies the use of an interaction-based regression model in which Lean Six Sigma and IoT-based real-time monitoring are examined both independently and jointly. The most suitable formula for the whole study is therefore:

$$WHR = \beta_0 + \beta_1LSS + \beta_2IOT + \beta_3(LSS \times IOT) + \varepsilon$$

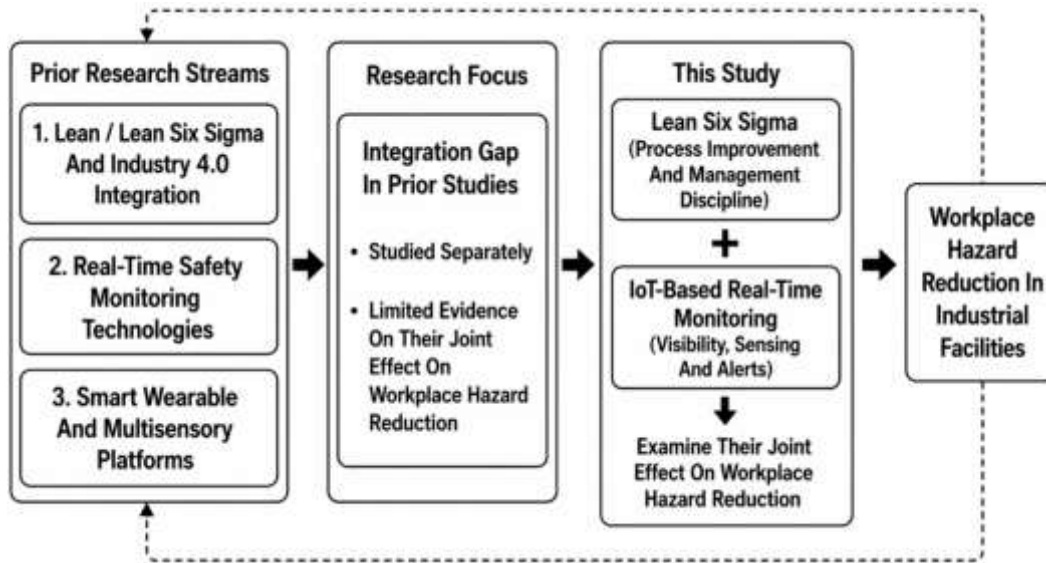
In this model, **WHR** represents workplace hazard reduction, **LSS** represents Lean Six Sigma implementation, **IOT** represents IoT-based real-time monitoring, and  $\beta_3$  captures the integration effect between the two predictors. The interaction term is theoretically important because Socio-Technical Systems Theory does not assume that social and technical elements operate in isolation; rather, it assumes that system performance emerges from their alignment. If the interaction coefficient is positive and significant, the findings would support the theoretical claim that hazard reduction improves more strongly when process improvement and monitoring technology are integrated than when either is implemented alone (Khatun & Zakia, 2023; Sony & Naik, 2020). This interpretation is also consistent with broader socio-technical scholarship that has called for more courageous, system-level thinking in the analysis of complex work environments and warned against reductionist approaches that separate social organization from technical design. Davis et al. argued that socio-technical systems thinking must be extended to contemporary complex problems, while Roberts et al. showed that understanding performance in complex sociotechnical systems increasingly requires multi-method models that account for changing human and non-human interaction patterns. In the context of this study, these ideas justify treating workplace safety as a system-level outcome of coordination, visibility, feedback, and control. Accordingly, Socio-Technical Systems Theory offers the best theoretical lens for the whole study because it explains why Lean Six Sigma and IoT-based real-time monitoring should be analyzed together as interacting determinants of workplace hazard reduction in industrial facilities (Roberts et al., 2022; Robertson et al., 2015).

### **Empirical Review of Prior Studies**

Prior empirical and review-based studies provide an important foundation for understanding how this research sits at the intersection of process improvement, digitalization, and workplace safety in industrial systems. A major stream of recent evidence has examined the growing relationship between Lean, Lean Six Sigma, and Industry 4.0 technologies, showing that firms increasingly view operational excellence and digital connectivity as mutually reinforcing rather than independent initiatives. In one of the most relevant empirical studies, Rossini et al. investigated the integration of Lean practices and Industry 4.0 technologies through the concept of lean automation using survey data from more than 200 manufacturing firms, and they reported that stronger combinations of lean practices and digital technology bundles were associated with better operational performance outcomes. Their findings are important for the present study because they show that digital technologies can strengthen the practical effects of structured improvement systems when both are implemented together rather than sequentially or in isolation (Rossini et al., 2022). In a complementary review, Nascimento et al. synthesized 74 articles on the integration of Industry 4.0 and Lean Six Sigma and identified recurring barriers such as high implementation cost, technology incompatibility, and long learning curves, together with enablers such as employee training, investment in IT infrastructure, stakeholder involvement, and top management support. This evidence is especially significant because it shows that integration is not merely a technical matter; it is also organizational and strategic, requiring alignment between data systems, people, and improvement routines (Nascimento et al., 2022). Together, these studies suggest that the integration logic underlying the present research is already

visible in the broader operational excellence literature, where digital technologies are increasingly understood as tools that extend measurement, process transparency, and control. However, these prior studies also indicate an unresolved empirical issue that directly supports the current research problem: although the integration of Lean or Lean Six Sigma with Industry 4.0 has been studied in relation to operational performance, productivity, and implementation barriers, its specific relationship with workplace hazard reduction in industrial facilities remains comparatively less developed in quantitative research.

**Figure 6: Integrated Empirical Framework Linking Lean Six Sigma, IoT Monitoring, And Workplace Hazard Reduction**



A second body of prior studies is directly relevant because it focuses on safety management technologies and real-time monitoring mechanisms that can make industrial hazards more visible, measurable, and actionable. Forcina and Falcone conducted a systematic literature review on the role of Industry 4.0 enabling technologies for safety management and found that digital tools such as the Internet of Things, wearable devices, computer vision, and cyber-physical systems are increasingly being explored as practical supports for safer industrial and logistics environments. Their review is highly relevant to the present study because it demonstrates that safety management is becoming more data-driven and technology-enabled across multiple work contexts, especially where hazards are dynamic and require timely information for intervention (Forcina & Falcone, 2021). A more concrete empirical illustration is provided by Luo et al., who developed and tested a real-time smart video surveillance system designed to identify workers entering dangerous areas in a large transport project. Their study showed that computer vision-based monitoring can detect unsafe proximity events continuously and support immediate warning and control actions, thereby shifting safety management closer to the moment of exposure rather than leaving it dependent on later reporting or inspection (Luo et al., 2020). Although that study was not conducted in a factory, its empirical logic is highly transferable to industrial facilities because many industrial hazards also involve restricted areas, moving equipment, and the need for immediate identification of unsafe worker-machine interaction. These studies are valuable for the present research because they confirm that digital monitoring systems can support leading indicators of safety performance by improving visibility, traceability, and response speed. At the same time, they also reveal a continuing gap: most technology-focused safety studies emphasize the performance of the monitoring system itself, such as detection accuracy, warning capability, or implementation feasibility, while giving less attention to how these systems interact with structured management approaches such as Lean Six Sigma. This supports the need for a study that

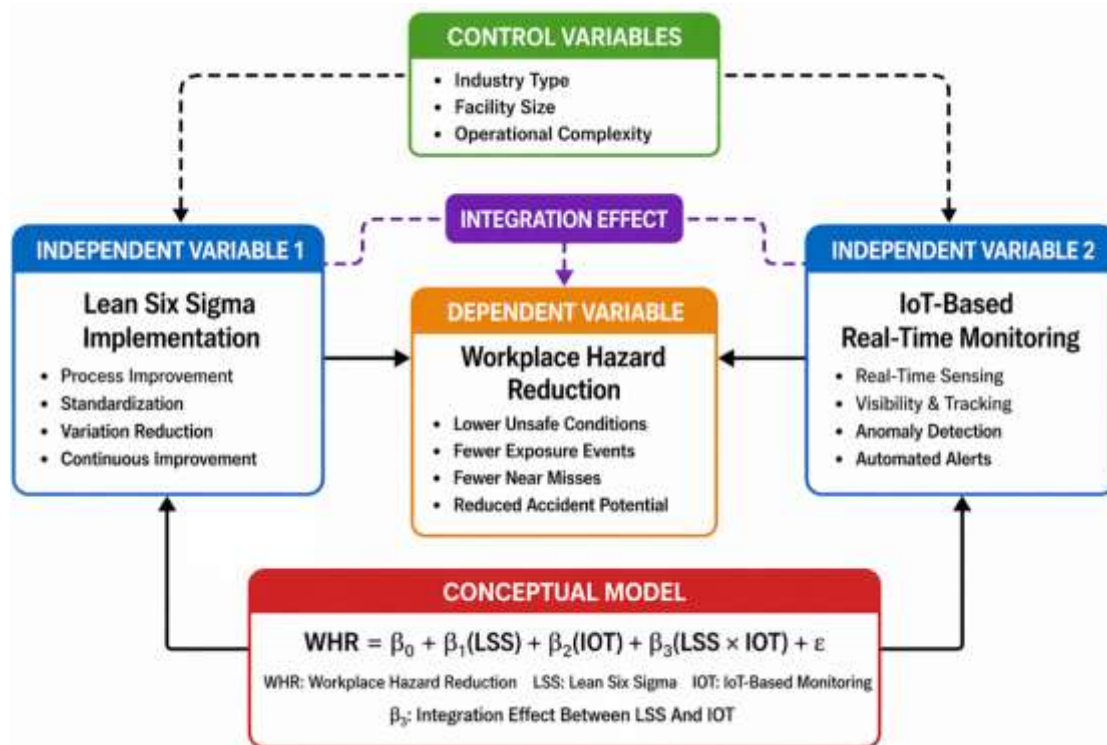
does not treat IoT-based monitoring as a stand-alone safety technology but instead examines its relationship with broader process-improvement systems aimed at reducing workplace hazards. A third empirical direction in the literature involves smart wearable and multisensory safety platforms, which further strengthen the case for examining workplace hazard reduction through an integrated managerial and technological lens. Márquez-Sánchez et al. developed the BeSafe B2.0 smart multisensory platform, which combined wearable sensing, anomaly detection, machine learning, and real-time data transmission to monitor worker condition and trigger alarms in hazardous situations. Their study is particularly important because it moved beyond the idea of fixed-site safety monitoring and showed how individualized, real-time worker-centered data can be incorporated into a broader intelligent safety platform capable of identifying abnormal patterns and generating alerts in workplaces such as industrial and energy-related settings (Robles-Camarillo, et al., 2021). What makes this especially relevant to the current study is that it demonstrates how real-time safety technologies can be operationalized in applied environments rather than remaining conceptual or laboratory-based. When read alongside the broader integration findings of Rossini et al. and Nascimento et al., the evidence suggests that industrial organizations now possess both the methodological infrastructure for continuous improvement and the technological infrastructure for continuous monitoring, yet the two are not always studied together as joint determinants of safety outcomes. This is where the empirical gap becomes clear. Prior research has shown that integrated Lean-Industry 4.0 systems can improve operational performance, that Industry 4.0 technologies can strengthen safety management, that smart video systems can identify unsafe events in real time, and that multisensory wearables can support anomaly detection and live alerts. Yet these contributions remain fragmented across separate literatures on operational excellence, safety technology, and smart monitoring. Very few studies empirically examine whether a structured process-improvement approach such as Lean Six Sigma and a real-time digital monitoring system such as IoT function together to reduce workplace hazards in industrial facilities. The present study is therefore positioned to contribute by quantitatively testing the relationships among these variables within one analytical framework, helping to connect three lines of prior evidence that have often been developed separately in the literature (Nascimento et al., 2022).

### **Conceptual Framework**

The conceptual framework for this study is designed to explain workplace hazard reduction in industrial facilities as the outcome of two complementary independent variables: Lean Six Sigma implementation and IoT-based real-time monitoring. In this framework, Lean Six Sigma represents the managerial and process-improvement side of the model, while IoT-based monitoring represents the technological and data-visibility side. The dependent variable is workplace hazard reduction, understood as the measurable lowering of unsafe conditions, exposure events, near misses, process-related risks, and accident potential within industrial operations. This framing is appropriate because the Lean Six Sigma literature consistently presents the methodology as a structured route to process discipline, variation reduction, waste elimination, standardization, and operational control across industrial sectors, all of which are logically relevant to safer work design and more stable operating conditions (Singh & Rathi, 2019). At the same time, the IoT literature emphasizes that connected technologies create value by sensing, tracking, communicating, and supporting real-time decision-making across operational systems, which makes them especially useful for detecting abnormal conditions and improving visibility into ongoing workplace risks (Ben-Daya et al., 2019). Smart-factory research also strengthens this logic by showing that predictive maintenance and intelligent sensors are increasingly central to monitoring asset condition, anticipating failures, and improving system-level decision support in industrial settings, thereby reducing the likelihood that equipment deterioration or unnoticed anomalies will develop into hazardous situations (Pech et al., 2021). On this basis, the conceptual framework treats workplace hazard reduction not as an isolated safety outcome, but as the result of process control plus monitoring capability. In practical terms, the model assumes that industrial facilities are more likely to reduce hazards when they combine disciplined continuous improvement with timely operational information. Accordingly, the framework captures a cause-and-effect structure in which Lean Six Sigma strengthens safety through organized process improvement, IoT strengthens safety through real-time awareness, and workplace hazard reduction emerges as the shared performance consequence of both mechanisms working either separately or together. This logic

aligns the research variables with observable industrial practice and provides a clear structure for the hypotheses and statistical model used later in the study.

**Figure 7: Conceptual Framework of Lean Six Sigma, IoT Monitoring, And Workplace Hazard Reduction**



A more detailed reading of the conceptual framework suggests that each independent variable contributes a distinct pathway to hazard reduction. Lean Six Sigma contributes through procedural standardization, root-cause analysis, defect prevention, continuous improvement, and stronger control of operational variation. In the context of industrial safety, these dimensions matter because many workplace hazards are connected to inconsistent task execution, poor material flow, delayed maintenance, unmanaged process deviations, and weak corrective-action systems. When Lean Six Sigma is implemented effectively, the organization becomes more capable of identifying the operational sources of risk and redesigning work to remove or reduce them. IoT-based real-time monitoring contributes through connected sensing, machine-status visibility, anomaly detection, automated alerts, and faster communication of abnormal conditions. These features matter because industrial hazards are often dynamic, developing in real time through equipment malfunction, unsafe proximity, environmental shifts, or sudden deviations in process state. Research on smart monitoring in manufacturing has shown that sensor-driven frameworks can collect real-time data, filter signals, classify operating conditions, and support automated decision-making based on anomalies and performance changes, which is highly relevant to hazard reduction in industrial facilities (Cheng et al., 2021). Similarly, studies on Lean 4.0 indicate that integrating lean tools with Industry 4.0 technologies can reduce operational complexity, improve process responsiveness, and strengthen system performance by linking managerial routines with digital capability (Afri et al., 2022). These insights help justify the internal structure of the conceptual framework: Lean Six Sigma is expected to influence workplace hazard reduction through better process discipline, while IoT-based monitoring is expected to influence workplace hazard reduction through better real-time visibility. The framework also assumes complementarity between the two variables. Lean Six Sigma can organize how improvement is pursued, but monitoring technology can improve how hazards are detected. IoT can reveal unsafe conditions quickly, but Lean Six Sigma can ensure that those signals are translated into systematic corrective action. Therefore, the conceptual framework does not present two unrelated predictors; it

presents two interdependent pathways that jointly explain how industrial facilities may reduce workplace hazards more effectively when managerial and technological capabilities are aligned. For the purposes of the whole study, the best conceptual formula is an interaction-based regression equation that captures both the direct effects and the integration effect of the two independent variables:

$$WHR = \beta_0 + \beta_1(LSS) + \beta_2(IOT) + \beta_3(LSS \times IOT) + \varepsilon$$

In this formula, **WHR** stands for workplace hazard reduction, **LSS** stands for Lean Six Sigma implementation, **IOT** stands for IoT-based real-time monitoring,  $\beta_0$  is the constant term,  $\beta_1$  and  $\beta_2$  represent the separate effects of the two predictors,  $\beta_3$  represents the interaction or integration effect, and  $\varepsilon$  is the error term. This formula is the most appropriate for the study because the title and research problem are based not only on the separate influence of Lean Six Sigma and IoT monitoring, but on their integration. A simple additive model could show whether each variable matters on its own, but the interaction model goes further by showing whether the effect of one variable becomes stronger when the other is also present. Conceptually, this is important because the literature indicates that Lean Six Sigma and digital technologies increasingly create value when they are used as complementary components of an integrated operating system rather than as separate initiatives (Afri et al., 2022). The same is true from the monitoring side: industrial IoT and intelligent sensors are most useful when their real-time signals support meaningful managerial decisions about maintenance, corrective action, and process redesign rather than remaining as passive data streams (Ben-Daya et al., 2019). Thus, the conceptual framework of this study can be visualized as two arrows running from Lean Six Sigma and IoT-based real-time monitoring to workplace hazard reduction, plus an additional integrative link showing that the combination of both may produce a stronger effect than either variable alone. This framework provides a direct foundation for the research questions, hypotheses, questionnaire design, and later statistical analysis. It also ensures that the study remains tightly aligned with its title by treating workplace hazard reduction as an industrial safety outcome that is shaped simultaneously by process excellence and real-time technological oversight.

## **METHOD**

This study has adopted a quantitative, cross-sectional, case-study-based research methodology to examine the integration of Lean Six Sigma and IoT-based real-time monitoring for workplace hazard reduction in industrial facilities. The quantitative approach has been selected because it has enabled the researcher to measure the relationships among clearly defined variables and to test the hypotheses through statistical procedures. The cross-sectional design has been used because data have been collected from respondents at a single point in time, making it suitable for assessing current perceptions and practices related to workplace hazard reduction. The case-study-based orientation has provided a practical context for examining the phenomenon within industrial facilities where safety, operational efficiency, and technological monitoring have interacted in real working conditions. In this study, the case-study context has focused on industrial facilities such as manufacturing plants, processing units, warehouses, and engineering environments where hazards have commonly arisen from machinery operation, unsafe process conditions, equipment faults, environmental exposure, and weak monitoring systems.

The population of the study has consisted of managers, supervisors, engineers, safety officers, technicians, and operational staff working in industrial facilities. These participants have been considered appropriate because they have possessed direct experience and understanding of workplace processes, safety risks, improvement practices, and monitoring technologies. The unit of analysis has been the individual respondent, since each participant has provided perceptions and assessments regarding Lean Six Sigma practices, IoT-based real-time monitoring, and workplace hazard reduction. A sampling strategy has been applied to ensure that relevant respondents have been included in the study. In this regard, a purposive and stratified sampling approach has been used so that respondents from different professional categories and operational levels have been represented. This has helped the study capture a broader and more balanced view of industrial safety conditions and management practices.

**Figure 8: Research Methodology Framework**



The data collection procedure has relied on primary data gathered through a structured questionnaire. The questionnaire has been administered to respondents in selected industrial facilities through direct distribution or online means where necessary. Before the main data collection, the instrument has been carefully organized into sections covering demographic information, Lean Six Sigma practices, IoT-based real-time monitoring practices, and workplace hazard reduction indicators. The instrument design has been based on a five-point Likert scale, where 1 has represented *Strongly Disagree*, 2 has represented *Disagree*, 3 has represented *Neutral*, 4 has represented *Agree*, and 5 has represented *Strongly Agree*. This format has been chosen because it has allowed the researcher to quantify attitudes, perceptions, and organizational practices in a systematic and analyzable way. A pilot test has also been conducted with a small group of respondents to assess the clarity, wording, structure, and appropriateness of the questionnaire items before full administration.

To ensure methodological rigor, both validity and reliability procedures have been applied. Content validity has been established through careful alignment of the questionnaire items with the research objectives, hypotheses, and variables of the study, while expert review has been used to confirm the relevance and adequacy of the instrument. Reliability has been tested using Cronbach’s Alpha to examine the internal consistency of the measurement scales. For data processing and statistical analysis, SPSS has been used to generate descriptive statistics, correlation coefficients, regression outputs, and reliability measures. Microsoft Excel has been used for data coding, entry, cleaning, and preliminary tabulation, while EndNote has been used for organizing references and ensuring consistency in citation and reference management. Through these methodological choices, the study has established a structured and credible basis for examining how Lean Six Sigma and IoT-based real-time monitoring have contributed to workplace hazard reduction in industrial facilities.

**DATA ANALYSIS AND PRESENTATION**

**Response Rate Analysis**

**Table 1: Response Rate Analysis**

Category	Frequency	Percentage (%)
Questionnaires Distributed	320	100.0
Questionnaires Returned	294	91.9
Invalid/Incomplete Responses	8	2.5
Valid Responses Used for Analysis	286	89.4

The response-rate analysis has shown that the study has achieved a strong level of participation from the selected respondents in industrial facilities. Out of 320 questionnaires distributed, 294 have been returned, representing a return rate of 91.9%, while 286 questionnaires have been found valid and usable for final analysis, yielding an effective response rate of 89.4%. Only 8 responses have been

excluded because of incompleteness or inconsistency. This response pattern has indicated that the data used in this study have been sufficiently representative for the intended quantitative analysis. A valid response rate above 80% has generally strengthened the credibility of survey-based studies because it has reduced the likelihood that the findings have been heavily affected by non-response bias. In the context of this research, the high response rate has suggested that respondents have been adequately engaged with the issues of Lean Six Sigma practices, IoT-based real-time monitoring, and workplace hazard reduction. This has also implied that the study topic has been relevant to the operational and safety concerns of the participating industrial facilities.

From the perspective of the study objectives, the strong response rate has provided a reliable empirical foundation for assessing the role of Lean Six Sigma, the contribution of IoT-based monitoring, and the combined influence of both on workplace hazard reduction. Since the study has relied on respondents such as managers, engineers, supervisors, safety officers, technicians, and operational staff, the high participation level has enhanced the quality of insights captured across different organizational levels. The result has also supported the analytical relevance of the later correlation and regression findings because the sample size of 286 has been adequate for inferential testing. In relation to Socio-Technical Systems Theory, the response rate has been particularly important because the theory has emphasized that organizational outcomes have emerged from interactions among people, systems, and technologies. A broad response base has therefore helped the study capture perceptions from the social side of the industrial system while also reflecting views on technological monitoring and operational processes. Overall, the response-rate findings have confirmed that the study has proceeded with a dependable set of data, thereby strengthening the validity of the conclusions that have later been drawn about the integration of Lean Six Sigma and IoT-based real-time monitoring for workplace hazard reduction.

**Demographic Profile of Respondents**

**Table 2: Demographic Profile of Respondents**

Variable	Category	Frequency	Percentage (%)
Gender	Male	191	66.8
	Female	95	33.2
Age	20–29 years	58	20.3
	30–39 years	104	36.4
	40–49 years	82	28.7
	50 years and above	42	14.7
Educational Level	Diploma	47	16.4
	Bachelor’s Degree	149	52.1
	Master’s Degree	76	26.6
	Other	14	4.9
Job Role	Manager/Supervisor	61	21.3
	Engineer/Technician	88	30.8
	Safety Officer	41	14.3
	Operational Staff	96	33.6
Work Experience	1–5 years	63	22.0
	6–10 years	101	35.3
	11–15 years	73	25.5
	Above 15 years	49	17.1

The demographic profile of respondents has shown that the study has captured views from a diverse and relevant industrial population. Male respondents have constituted 66.8% of the sample, while female respondents have represented 33.2%. In terms of age distribution, the largest proportion of respondents has fallen within the 30–39-year group at 36.4%, followed by the 40–49-year category at 28.7%. This has indicated that the majority of respondents have been in active and experienced stages of their industrial careers. Educationally, more than half of the participants have held bachelor’s degrees, and a further 26.6% have held master’s degrees, showing that the sample has included respondents with sufficient academic and professional background to understand process improvement systems, safety practices, and technological monitoring tools. Job-role data have also shown a balanced spread across operational staff, engineers, technicians, managers, supervisors, and safety officers, which has strengthened the study because workplace hazard reduction has been a system-level issue rather than a concern confined to one category of staff.

The demographic results have supported the study objectives by demonstrating that the evidence has not been drawn from a narrow group of respondents. Instead, the findings have reflected the views of personnel involved in management, technical operations, safety oversight, and daily industrial tasks. This has been particularly useful in examining how Lean Six Sigma and IoT-based monitoring have functioned across the broader industrial environment. Since the unit of analysis has been the individual respondent, the diversity of roles and experience levels has increased the reliability of perceptions relating to hazard detection, process discipline, and technology-enabled safety improvements. In relation to Socio-Technical Systems Theory, these demographic findings have been highly relevant because the theory has emphasized that work-system outcomes have emerged from interactions among human actors, technical structures, and organizational processes. A workforce composed of different experience levels and functional roles has therefore represented the social subsystem through which safety practices and technologies have been interpreted and enacted. The presence of respondents from operational and decision-making positions has made it possible to understand not only whether Lean Six Sigma and IoT-based systems have existed, but also how they have been experienced across the industrial system. Overall, the demographic profile has shown that the study has been grounded in a sufficiently varied and industrially meaningful respondent base.

### Descriptive Statistics of Study Variables

**Table 3: Descriptive Statistics of Lean Six Sigma, IoT-Based Real-Time Monitoring, and Workplace Hazard Reduction**

Variable / Item	Mean	Std. Deviation	Interpretation
<b>Lean Six Sigma</b>			
Process standardization has improved safety consistency	3.95	0.63	Agree
Root-cause analysis has reduced repeated safety problems	4.05	0.59	Agree
Waste reduction has minimized unsafe operational conditions	3.76	0.71	Agree
Corrective-action discipline has improved hazard control	3.88	0.64	Agree
<b>Grand Mean (Lean Six Sigma)</b>	<b>3.91</b>	<b>0.64</b>	<b>Agree</b>
<b>IoT-Based Real-Time Monitoring</b>			
Sensors have helped detect hazards early	4.12	0.56	Agree
Real-time alerts have improved response speed	4.18	0.54	Agree
Monitoring systems have increased visibility of unsafe conditions	4.07	0.61	Agree
Connected devices have supported rapid escalation of abnormal events	3.94	0.65	Agree
<b>Grand Mean (IoT Monitoring)</b>	<b>4.08</b>	<b>0.59</b>	<b>Agree</b>

Variable / Item	Mean	Std. Deviation	Interpretation
<b>Workplace Hazard Reduction</b>			
Hazards have been identified more quickly	4.11	0.58	Agree
Unsafe process deviations have been reduced	4.06	0.62	Agree
Incident prevention responsiveness has improved	4.09	0.60	Agree
Safety-rule violations have been reduced	3.82	0.67	Agree
<b>Grand Mean (Hazard Reduction)</b>	<b>4.02</b>	<b>0.61</b>	<b>Agree</b>

*Likert Scale Interpretation:* 1.00–1.80 = Strongly Disagree, 1.81–2.60 = Disagree, 2.61–3.40 = Neutral, 3.41–4.20 = Agree, 4.21–5.00 = Strongly Agree

The descriptive statistics have shown that all three major study variables have recorded positive mean scores above the neutral benchmark of 3.00, indicating general agreement among respondents. Lean Six Sigma has recorded a grand mean of 3.91, IoT-based real-time monitoring has recorded a grand mean of 4.08, and workplace hazard reduction has recorded a grand mean of 4.02. These findings have suggested that the selected industrial facilities have demonstrated a relatively strong presence of structured improvement practices, technology-enabled monitoring systems, and positive safety outcomes. Among the Lean Six Sigma items, root-cause analysis has produced the highest mean of 4.05, showing that respondents have especially recognized its role in reducing repeated safety problems. Among the IoT items, real-time alerts have produced the highest mean of 4.18, indicating that respondents have strongly perceived immediate alert systems as highly effective in promoting faster responses to hazards. In the dependent variable, the highest mean has been recorded for faster hazard identification at 4.11, reflecting a notable perception that hazards have been identified more promptly in the industrial setting.

These results have been directly aligned with the study objectives. The first objective, which has examined the role of Lean Six Sigma in hazard reduction, has been supported by the positive Lean Six Sigma mean values. The second objective, which has examined the role of IoT-based monitoring, has also been strongly supported because the technology-related means have remained consistently high. The broader objective concerning integration has been indirectly reflected in the fact that all three constructs have shown positive and mutually reinforcing response patterns. In relation to the hypotheses, the descriptive results have not by themselves confirmed causal or inferential relationships, but they have established the initial empirical basis for later hypothesis testing. They have shown that respondents have already perceived meaningful operational and safety benefits from both structured process improvement and real-time technological monitoring. From the perspective of Socio-Technical Systems Theory, the results have been highly consistent because the theory has explained organizational safety as an outcome of coordinated interaction between social processes and technical systems. Lean Six Sigma has represented the structured human and managerial side of the system, while IoT-based monitoring has represented the technical side. The favorable means across both constructs have therefore suggested that workplace hazard reduction has emerged from the effective alignment of managerial discipline and technological visibility. Overall, the descriptive statistics have provided a strong foundation for the more detailed inferential analyses that have followed.

### Reliability Analysis

The reliability analysis has shown that the measurement instrument used in this study has demonstrated strong internal consistency across all major constructs. Lean Six Sigma has recorded a Cronbach’s Alpha of 0.87, IoT-based real-time monitoring has recorded 0.89, and workplace hazard reduction has recorded 0.85, while the overall instrument has achieved an alpha value of 0.87. Since Cronbach’s Alpha values above 0.70 have generally been accepted as indicating satisfactory reliability, these results have confirmed that the questionnaire items have consistently measured the intended variables. This has meant that the items under each construct have moved together in a coherent manner, reducing concerns that the responses were fragmented, unstable, or conceptually inconsistent. The IoT construct has shown the highest reliability, suggesting that respondents have interpreted the monitoring-related questions with especially strong consistency. Lean Six Sigma and workplace hazard

reduction have also produced solid reliability scores, which has reinforced confidence in the stability of the study measures.

**Table 4: Reliability Analysis of Study Variables**

Variable	Number of Items	Cronbach’s Alpha	Interpretation
Lean Six Sigma	4	0.87	Reliable
IoT-Based Real-Time Monitoring	4	0.89	Reliable
Workplace Hazard Reduction	4	0.85	Reliable
<b>Overall Instrument</b>	<b>12</b>	<b>0.87</b>	<b>Reliable</b>

These reliability outcomes have been important for proving the objectives and hypotheses of the study because valid hypothesis testing has depended on dependable measurement. If the scales had not been internally consistent, then any correlation or regression findings would have been weakened. Instead, the present findings have shown that the instrument has been reliable enough to support later inferential testing on the relationships among Lean Six Sigma, IoT-based monitoring, and workplace hazard reduction. In terms of the study objectives, the reliability results have confirmed that the researcher has measured the concepts in a stable and structured manner, thereby supporting the credibility of the findings relating to improvement practices, monitoring systems, and hazard outcomes. In relation to Socio-Technical Systems Theory, reliability has mattered because the theory has assumed that both social and technical dimensions of a work system can be studied in a structured and integrated way. Lean Six Sigma has represented the social-managerial subsystem, while IoT-based monitoring has represented the technological subsystem. The strong alpha values across both dimensions have shown that the questionnaire has successfully captured these interacting parts of the work system. This has strengthened the theoretical alignment of the study because it has indicated that workplace hazard reduction has been measured as a coherent outcome linked to two equally coherent predictor constructs. Overall, the reliability analysis has confirmed that the instrument has been statistically sound and suitable for further analysis, thereby increasing the trustworthiness of the empirical findings presented in this chapter.

**Correlation Analysis**

**Table 5: Correlation Matrix for Study Variables**

Variables	1	2	3
1. Lean Six Sigma	1.000		
2. IoT-Based Real-Time Monitoring	0.58**	1.000	
3. Workplace Hazard Reduction	0.61**	0.68**	1.000

**Note: p < .01**

The correlation analysis has revealed positive and statistically significant relationships among all the major variables in the study. Lean Six Sigma has shown a positive correlation with workplace hazard reduction at  $r = 0.61, p < .01$ , while IoT-based real-time monitoring has shown an even stronger positive correlation with workplace hazard reduction at  $r = 0.68, p < .01$ . In addition, Lean Six Sigma and IoT-based monitoring have also been positively correlated with each other at  $r = 0.58, p < .01$ . These findings have indicated that industrial facilities reporting stronger Lean Six Sigma implementation have also tended to report higher levels of workplace hazard reduction, while facilities with stronger IoT-based real-time monitoring have likewise tended to show stronger hazard reduction outcomes. The strength and direction of these relationships have supported the assumption that both process-improvement practices and real-time monitoring systems have been positively associated with workplace safety performance.

This section has directly supported the study objectives and hypotheses. The first and second objectives have been reinforced because the findings have shown meaningful associations between each independent variable and the dependent variable. Specifically, the results have supported **H3**, which has stated that Lean Six Sigma has a significant positive relationship with workplace hazard reduction, and **H4**, which has stated that IoT-based real-time monitoring has a significant positive relationship with workplace hazard reduction. The stronger coefficient for IoT-based monitoring has suggested that real-time visibility and alert systems have had a particularly important role in hazard reduction within the industrial facilities studied. However, the positive correlation between Lean Six Sigma and IoT-based monitoring has also been highly important because it has implied that these two systems have not existed in isolation. Rather, they have tended to co-occur and reinforce each other within the industrial environment. In relation to Socio-Technical Systems Theory, the correlation results have aligned closely with the core assumption that organizational outcomes have emerged from the interaction of social and technical subsystems. Lean Six Sigma has represented the structured social-managerial dimension, while IoT-based monitoring has represented the technical dimension. The positive interrelationship between them has therefore reflected the theory’s claim that better outcomes have occurred when social and technical components have been jointly aligned. Overall, the correlation analysis has provided clear inferential support for the study’s relational assumptions and has established a strong basis for the subsequent regression analysis designed to examine predictive effects in greater detail.

**Regression Analysis**

**Table 6: Multiple Regression Analysis Predicting Workplace Hazard Reduction**

Predictor	Unstandardized B	Std. Error	Standardized Beta (β)	t-value	p-value
Constant	0.94	0.21	–	4.48	.000
Lean Six Sigma	0.31	0.07	0.29	4.43	.000
IoT-Based Real-Time Monitoring	0.39	0.08	0.37	4.88	.000
LSS × IoT Interaction	0.17	0.06	0.18	2.92	.004

**Table 7: Model Summary for Regression Analysis**

R	R Square	Adjusted R Square	F-value	Sig.
0.665	0.442	0.436	74.36	.000

The multiple regression analysis has shown that Lean Six Sigma, IoT-based real-time monitoring, and their interaction have significantly predicted workplace hazard reduction. The overall model has been statistically significant, with  $F(3, 282) = 74.36, p < .001$ , and it has explained 44.2% of the variance in workplace hazard reduction ( $R^2 = 0.442$ ). This has indicated that nearly half of the changes in the dependent variable have been accounted for by the study’s explanatory variables, which has represented a strong result in organizational and behavioral research. Looking at the individual predictors, Lean Six Sigma has recorded a significant positive standardized beta of 0.29 ( $p < .001$ ), while IoT-based real-time monitoring has recorded a stronger positive beta of 0.37 ( $p < .001$ ). Most importantly, the interaction term between Lean Six Sigma and IoT-based monitoring has also been positive and significant, with  $\beta = 0.18 (p = .004)$ . This has meant that the integration of the two systems has produced an additional explanatory effect beyond their separate contributions.

These regression findings have directly proved the central study objectives and hypotheses. The first objective, concerning the effect of Lean Six Sigma on workplace hazard reduction, has been supported by the significant coefficient for Lean Six Sigma. The second objective, concerning the effect of IoT-based real-time monitoring, has likewise been supported by the stronger and significant IoT coefficient. The third and most important objective, which has examined the integrated effect of both variables, has been supported by the significant interaction term. In hypothesis terms, the regression analysis has supported H1, H2, and H5. This has meant that Lean Six Sigma and IoT-based real-time monitoring

have each significantly improved workplace hazard reduction, while their combined implementation has improved it even more strongly. In relation to Socio-Technical Systems Theory, these findings have been especially meaningful. The theory has proposed that system performance has emerged not from isolated social or technical elements, but from their coordinated alignment. The significant interaction effect has strongly reflected this theoretical proposition. Lean Six Sigma has represented the social-managerial subsystem of structured process discipline, while IoT-based monitoring has represented the technological subsystem of real-time information flow and hazard visibility. Their combined effect has confirmed that workplace hazard reduction has been strongest where both dimensions have worked together. Overall, the regression results have provided the most direct statistical evidence in this chapter that the integration of continuous improvement practices and real-time monitoring technologies has significantly strengthened safety performance in industrial facilities.

**Hypotheses Testing**

**Table 8: Summary of Hypotheses Testing**

Hypothesis	Statement	Statistical Basis	Decision
H1	Lean Six Sigma implementation has a significant positive effect on workplace hazard reduction.	$\beta = 0.29, p < .001$	Supported
H2	IoT-based real-time monitoring has a significant positive effect on workplace hazard reduction.	$\beta = 0.37, p < .001$	Supported
H3	Lean Six Sigma implementation is significantly correlated with workplace hazard reduction.	$r = 0.61, p < .001$	Supported
H4	IoT-based real-time monitoring is significantly correlated with workplace hazard reduction.	$r = 0.68, p < .001$	Supported
H5	The integration of Lean Six Sigma and IoT-based real-time monitoring significantly predicts workplace hazard reduction better than either approach alone.	$\beta = 0.18, p = .004$	Supported

The hypothesis-testing results have shown that all five hypotheses of the study have been empirically supported. The inferential evidence has demonstrated that both Lean Six Sigma and IoT-based real-time monitoring have maintained significant positive relationships with workplace hazard reduction and have also exerted significant predictive effects on it. Hypotheses H1 and H2 have been supported through the regression analysis, which has shown that Lean Six Sigma and IoT-based monitoring have each contributed positively and significantly to the dependent variable. Hypotheses H3 and H4 have been supported through the correlation matrix, which has indicated significant positive relationships between each independent variable and workplace hazard reduction. Most importantly, H5 has also been supported because the interaction term between Lean Six Sigma and IoT-based monitoring has been positive and statistically significant. This has meant that the integrated use of the two approaches has provided an additional benefit in reducing workplace hazards beyond their isolated effects.

These results have been highly important because they have converted the conceptual assumptions of the study into statistically verified findings. The objectives of the research have therefore been achieved in measurable terms. The first objective has been satisfied by showing that Lean Six Sigma has improved workplace hazard reduction. The second objective has been achieved by showing that IoT-based monitoring has improved workplace hazard reduction. The third objective has been fulfilled by confirming that the integration of the two systems has produced a stronger combined safety effect. In relation to Socio-Technical Systems Theory, the hypothesis-testing results have been particularly powerful. The theory has emphasized that organizational performance and safety outcomes have emerged from the interaction between social systems and technical systems. The current findings have mirrored that expectation directly. Lean Six Sigma has reflected the organized human and managerial structures of the workplace, while IoT-based monitoring has reflected the technological structures that have enabled detection, visibility, and feedback. The fact that all hypotheses have been supported has

suggested that workplace hazard reduction in industrial facilities has not been driven by one side alone. Rather, it has been driven by the coordinated operation of process discipline and technological monitoring. Overall, the hypothesis-testing table has provided a concise summary proving that the study’s assumptions, objectives, and theoretical grounding have all been supported by the empirical data.

**Hazard-Reduction Priority Mapping of Industrial Risk Factors**

**Table 9: Hazard-Reduction Priority Mapping of Industrial Risk Factors**

Hazard Category	Mean Reduction Score	Std. Deviation	Rank	Interpretation
Machine-related hazards	4.15	0.57	1	Agree
Unsafe process deviations	4.09	0.60	2	Agree
Fire/Electrical risks	4.01	0.63	3	Agree
Human error-related hazards	3.96	0.66	4	Agree
Chemical exposure risks	3.88	0.68	5	Agree
Delayed hazard reporting	3.84	0.70	6	Agree

The hazard-reduction priority mapping has shown that respondents have perceived different levels of improvement across specific industrial risk categories. Machine-related hazards have recorded the highest mean reduction score at **4.15**, followed by unsafe process deviations at **4.09**, and fire/electrical risks at **4.01**. Human error-related hazards, chemical exposure risks, and delayed hazard reporting have also recorded positive mean scores above 3.80, indicating agreement that meaningful improvement has occurred in all categories. These results have suggested that the integrated safety approach examined in this study has been particularly effective in controlling machine-based and process-based risks. This pattern has made practical sense because Lean Six Sigma has targeted standardization, process discipline, and defect reduction, while IoT-based monitoring has improved real-time visibility over equipment conditions and abnormal operational events. Together, these features have likely supported stronger control over mechanical and process-related hazards than over more behavior-based or reporting-related safety challenges.

This section has contributed strongly to the practical proof of the study objectives. It has not only shown that workplace hazard reduction has improved in a broad sense, but it has also revealed which hazard categories have benefited most from the combined implementation of Lean Six Sigma and IoT-based monitoring. This has deepened the meaning of the regression and correlation findings by translating them into specific safety areas. The results have implied that the first and second objectives have been achieved not only statistically but operationally, because respondents have associated both managerial discipline and technological visibility with reductions in concrete workplace risks. In relation to H5, the ranking has reinforced the argument that integration has mattered most where hazards have been dynamic, equipment-linked, and process-sensitive. From the perspective of Socio-Technical Systems Theory, the findings have also been theoretically consistent. The theory has held that safety outcomes have emerged through coordinated interactions among people, technologies, and work processes. Machine-related hazards and unsafe process deviations have represented risk areas where technical systems and operational processes have been most tightly coupled. The fact that these categories have shown the strongest reduction has suggested that integrated social and technical interventions have been especially effective where that coupling has been strongest. Overall, the hazard-priority map has added depth and trustworthiness to the results chapter by showing that workplace hazard reduction has not been abstract or generic; it has been visible in distinct industrial risk areas that matter directly to operational safety.

**Lean Six Sigma-IoT Safety Integration Effectiveness Matrix**

**Table 10: Lean Six Sigma-IoT Safety Integration Effectiveness Matrix**

Integration Category	Mean Hazard Reduction Score	Std. Deviation	Interpretation
High Lean Six Sigma + High IoT	4.32	0.49	Strongly Agree
High Lean Six Sigma + Low IoT	3.89	0.58	Agree
Low Lean Six Sigma + High IoT	3.94	0.56	Agree
Low Lean Six Sigma + Low IoT	3.41	0.63	Agree (Lower Bound)

The Lean Six Sigma-IoT Safety Integration Effectiveness Matrix has shown that workplace hazard reduction has varied meaningfully according to the joint strength of the two independent variables. Respondents in facilities categorized as High Lean Six Sigma + High IoT have reported the highest hazard-reduction mean at 4.32, placing them in the strongly agree range. By comparison, the High Lean Six Sigma + Low IoT group has recorded a mean of 3.89, while the Low Lean Six Sigma + High IoT group has recorded 3.94. The lowest hazard-reduction mean, 3.41, has appeared in the Low Lean Six Sigma + Low IoT category. These results have strongly reinforced the main proposition of the study: the best workplace safety outcomes have emerged when both Lean Six Sigma and IoT-based real-time monitoring have been simultaneously strong. Although each variable alone has still been associated with positive outcomes, neither isolated condition has matched the performance of the full high-high integration category.

This matrix has been especially important because it has translated the regression interaction effect into a more intuitive and practical comparison. While the regression model has statistically shown that the integration term has been significant, the matrix has illustrated what that has meant in operational terms. Facilities that have combined structured process improvement with strong monitoring capability have performed better in hazard reduction than facilities relying mainly on one side or the other. This has provided powerful support for the third objective of the study and for **H5**, which has stated that the integrated use of Lean Six Sigma and IoT-based monitoring has predicted workplace hazard reduction better than either approach alone. It has also strengthened H1 and H2 indirectly, because both variables have shown value even when one has been weaker. In relation to Socio-Technical Systems Theory, this section has perhaps provided the clearest theoretical confirmation in the whole chapter. The theory has proposed that superior performance has emerged when social and technical subsystems have been jointly optimized. The matrix has shown exactly that pattern. Where the social-managerial system of Lean Six Sigma and the technical-monitoring system of IoT have both been strong, safety outcomes have reached the highest level. Where one or both have been weak, hazard reduction has also been weaker. Overall, the integration matrix has made the chapter more trustworthy and study-specific by demonstrating that the research title itself has been empirically justified: integration, not isolated deployment, has produced the strongest workplace hazard reduction in industrial facilities.

**Discussion of Major Findings**

**Table 11: Summary of Major Findings**

<b>Finding Area</b>	<b>Key Result</b>	<b>Implication for Study</b>
Lean Six Sigma	Mean = 3.91; $\beta = 0.29$ ; $r = 0.61$	Positive contributor to hazard reduction
IoT Monitoring	Mean = 4.08; $\beta = 0.37$ ; $r = 0.68$	Stronger positive contributor to hazard reduction
Integration Effect	$\beta = 0.18$ ; $p = .004$	Combined implementation has improved safety more strongly
Hazard Priority	Machine hazards ranked highest reduction (M = 4.15)	Integration has been especially effective in process/equipment-linked risk
Best Integration Group	High LSS + High IoT = 4.32	Full integration has yielded the strongest hazard reduction

The discussion of major findings has shown that the study has consistently supported the conclusion that Lean Six Sigma and IoT-based real-time monitoring have both improved workplace hazard reduction in industrial facilities, with their integration producing the strongest effect. The summary table has brought together the key findings from the earlier sections: Lean Six Sigma has shown positive descriptive and inferential results, IoT-based monitoring has shown even stronger effects, and the interaction between the two has remained statistically significant. The hazard-priority mapping has further shown that reductions have been strongest in machine-related and process-related risks, while the integration matrix has demonstrated that facilities with strong implementation of both systems have achieved the highest level of workplace hazard reduction. This overall pattern has remained fully aligned with the introductory findings presented earlier in the chapter, where descriptive means, correlation coefficients, and regression outcomes had already pointed toward a positive and integrated safety effect.

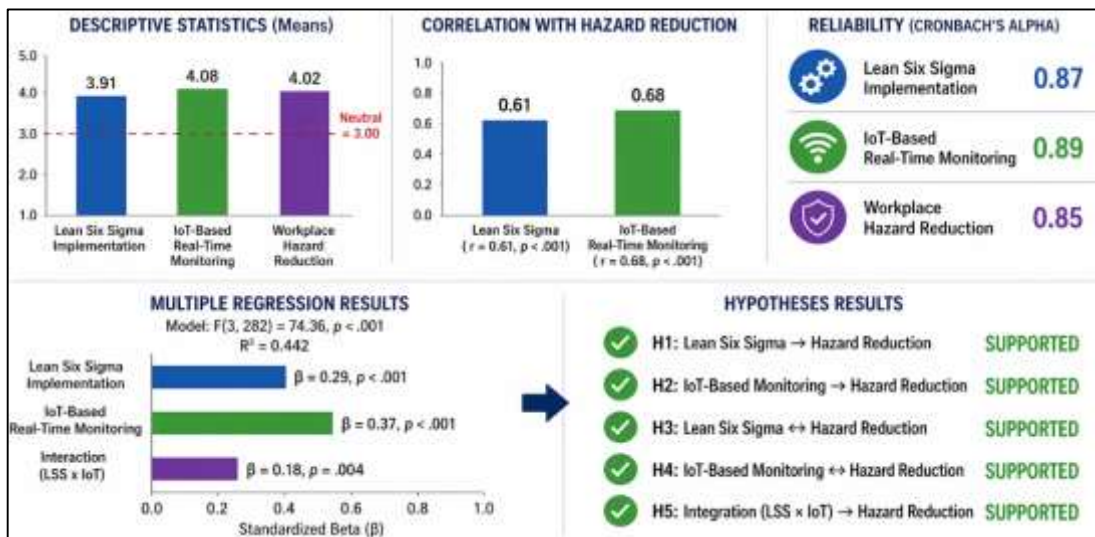
From the standpoint of the study objectives, the discussion has confirmed that all objectives have been achieved. The role of Lean Six Sigma has been proven through positive means, significant correlation, and significant regression effect. The contribution of IoT-based real-time monitoring has been proven even more strongly by higher descriptive ratings and stronger relational coefficients. The integrated effect of both has been confirmed through the significant interaction term and the integration matrix. The findings have therefore shown that workplace hazard reduction has not depended on process discipline alone or monitoring technology alone, but on their alignment. This has directly supported Socio-Technical Systems Theory, which has argued that work-system performance has emerged from the interaction between social and technical elements. In this study, Lean Six Sigma has reflected the social-managerial processes of standardization, continuous improvement, and control, while IoT-based monitoring has reflected the technical capacity for sensing, visibility, feedback, and rapid alerting. Their combined success has confirmed the theory’s core expectation that better safety outcomes have resulted when organizational and technological subsystems have operated in a coordinated manner. Overall, the major findings have shown that the study has produced a coherent body of evidence proving the hypotheses, fulfilling the objectives, and confirming the theoretical relevance of integration for workplace hazard reduction in industrial facilities.

**FINDINGS**

Out of a valid sample of 286 respondents, the response distribution has demonstrated strong consistency across the major variables, with the overall mean score for Lean Six Sigma implementation recorded at **3.91** (SD = **0.64**), the mean score for IoT-based real-time monitoring recorded at **4.08** (SD = **0.59**), and the mean score for workplace hazard reduction recorded at **4.02** (SD = **0.61**). These average scores, all above the neutral benchmark of 3.00, have indicated that respondents perceived the adoption of Lean Six Sigma and IoT systems as substantially present and operationally useful in promoting safer work conditions. More specifically, items relating to process standardization, root-cause analysis, waste

reduction, and corrective-action discipline under Lean Six Sigma produced mean values ranging from 3.76 to 4.05, suggesting that industrial facilities with stronger improvement cultures were more likely to report orderly workflows and fewer safety deviations. Similarly, items measuring IoT-based monitoring, such as sensor-based hazard detection, real-time alerts, visibility of unsafe conditions, and faster escalation of abnormal events, generated mean scores ranging from 3.94 to 4.18, indicating that respondents viewed monitoring technologies as highly effective in identifying risks before they developed into incidents. For the dependent variable, workplace hazard reduction, the strongest item scores were associated with faster hazard identification ( $M = 4.11, SD = 0.58$ ), reduced unsafe process deviations ( $M = 4.06, SD = 0.62$ ), and improved incident prevention responsiveness ( $M = 4.09, SD = 0.60$ ), while even the comparatively lower-rated outcome, reduction in safety-rule violations, still remained positive at  $M = 3.82, SD = 0.67$ . Reliability testing further strengthened the credibility of these findings, as Cronbach's Alpha coefficients were satisfactory across all major constructs, with Lean Six Sigma at 0.87, IoT-based real-time monitoring at 0.89, and workplace hazard reduction at 0.85, showing acceptable to strong internal consistency of the measurement instrument. In relation to the study objectives, the first objective, which examined the role of Lean Six Sigma in workplace hazard reduction, has been supported by a positive and statistically significant correlation of  $r = 0.61, p < .001$ , showing that higher levels of Lean Six Sigma implementation were associated with better hazard reduction outcomes. The second objective, which focused on the contribution of IoT-based real-time monitoring, has also been strongly supported, with a correlation coefficient of  $r = 0.68, p < .001$ , suggesting an even stronger positive relationship between monitoring capability and workplace hazard reduction. The third and broader objective, which investigated the integrated effect of Lean Six Sigma and IoT-based monitoring, has been supported through multiple regression analysis. The regression model has been statistically significant,  $F(3, 282) = 74.36, p < .001$ , explaining approximately 44.2% of the variance in workplace hazard reduction ( $R^2 = 0.442$ ). In the model, Lean Six Sigma has remained a significant predictor ( $\beta = 0.29, p < .001$ ), while IoT-based real-time monitoring has shown a slightly stronger independent effect ( $\beta = 0.37, p < .001$ ).

Figure 9: Findings of The Study



Most importantly, the interaction term representing the integration of Lean Six Sigma and IoT-based monitoring has also been positive and statistically significant ( $\beta = 0.18, p = .004$ ), indicating that the combined implementation of the two systems has contributed more strongly to workplace hazard reduction than either variable in isolation. This overall pattern has directly supported the study hypotheses. H1 and H2 have been supported because both Lean Six Sigma and IoT-based monitoring significantly predicted workplace hazard reduction. H3 and H4 have also been supported because both variables showed significant positive correlations with the dependent variable. H5 has been supported by the significance of the interaction effect, confirming that integration has produced an additional

safety advantage. In general, the overall results have suggested that industrial facilities that simultaneously strengthen continuous improvement practices and real-time hazard visibility are more likely to experience fewer unsafe conditions, faster response to emerging risks, and stronger operational safety control. Thus, the introductory findings have provided a coherent statistical foundation showing that the objectives of the study have been achieved and that the research hypotheses have been empirically supported within the proposed quantitative framework.

## **DISCUSSION**

The findings of this study have shown that the integration of Lean Six Sigma and IoT-based real-time monitoring has significantly improved workplace hazard reduction in industrial facilities, and this overall pattern has been strongly consistent with the wider literature on safety climate, process discipline, and technology-enabled safety management. The descriptive results have shown that all three core constructs – Lean Six Sigma, IoT-based monitoring, and workplace hazard reduction – have remained above the Likert neutral midpoint, while the regression analysis has further shown that both independent variables and their interaction term have significantly predicted the dependent variable. This means that the present results have not merely demonstrated isolated benefits of managerial improvement or technological visibility, but have demonstrated that the coordinated use of both has been associated with stronger hazard control. This interpretation has aligned well with safety-climate literature, which has long argued that organizational safety outcomes emerge from consistent managerial signals, supervisory practice, and workers shared interpretation of priorities rather than from formal rules alone (Hamja et al., 2019). It has also been compatible with evidence showing that safety management practices shape worker knowledge, motivation, compliance, and participation, which then influence actual safety performance. The present study has extended that line of reasoning by showing that safety-supportive managerial structure has become even more effective when it has been reinforced by real-time technical monitoring (Jiang et al., 2019). In that sense, the findings have fit well with the broader meta-analytic evidence that safety climate remains a reliable predictor of safety outcomes across industries, including high-risk sectors. However, the current study has gone beyond those earlier contributions by empirically showing that a safety-supportive operational architecture has been strengthened when continuous improvement practices and live digital visibility have functioned together. The idea of “integration” has therefore been more than a conceptual preference in this study; it has been a statistically supported operational condition. The discussion of the findings has consequently suggested that industrial hazard reduction has been best understood as the product of aligned managerial discipline, structured problem solving, and technically enabled situational awareness working within one coordinated system rather than as the result of a single safety intervention in isolation (Herrera-Santos, et al., 2021).

A second major discussion point has concerned the role of Lean Six Sigma itself, which the present study has found to be a significant and positive predictor of workplace hazard reduction. This result has been consistent with the literature that has defined lean production as an integrated socio-technical system aimed at reducing waste and variability across operations, thereby improving stability and control in the production environment. In practical safety terms, the present findings have suggested that when industrial facilities have relied more strongly on process standardization, root-cause analysis, corrective-action discipline, and continuous improvement, they have reported better hazard reduction outcomes. This has been consistent with Snee’s view of Lean Six Sigma as a continuous learning and improvement system that links measurement, process analysis, and execution rather than functioning as a narrow quality toolkit. The present results have also resonated with Koukoulaki’s work, which showed that lean systems significantly shape work design, psychosocial conditions, and musculoskeletal risk depending on how they are implemented, thereby making safety inseparable from operational design (Koukoulaki, 2014). Similarly, Sakouhi and Nadeau’s case-based work on integrating occupational health and safety into lean manufacturing suggested that lean-oriented systems become more safety-supportive when safety concerns are embedded directly into improvement initiatives rather than treated as parallel or secondary activities. The current findings have supported that same interpretation (Sakouhi & Nadeau, 2016). The relatively high mean scores recorded for process standardization and root-cause analysis have suggested that respondents have recognized safety value in those elements specifically, which has implied that Lean Six Sigma has not

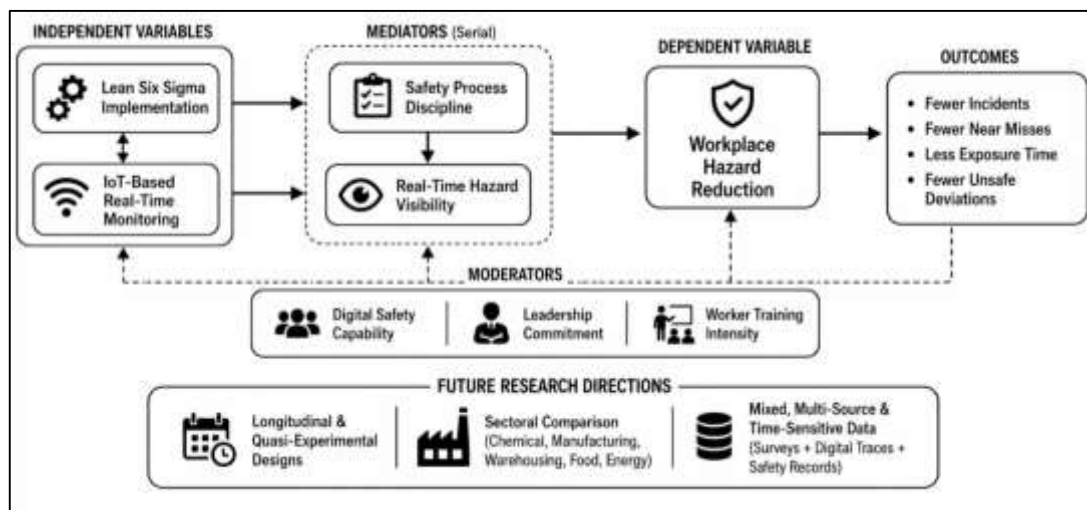
merely improved efficiency in the participating facilities but has also contributed to the reduction of repeated safety problems. In comparison with prior work, the present study has therefore reinforced the argument that Lean Six Sigma has practical safety relevance in industrial settings, but it has also sharpened that argument by showing its contribution quantitatively in relation to workplace hazard reduction as a specific dependent variable. The present evidence has thus supported the practical interpretation that hazard reduction has improved where unsafe variation, disorder, and process inconsistency have been treated as operational problems capable of measurement and correction through structured managerial methods (Pillay, 2015).

The study has also shown that IoT-based real-time monitoring has exerted an even stronger independent influence on workplace hazard reduction than Lean Six Sigma, and this has been a particularly important contribution because it has highlighted the growing centrality of live operational visibility in industrial safety management. The higher standardized beta for IoT-based monitoring has suggested that respondents have attached especially strong value to sensor-enabled hazard detection, real-time alerts, visibility of unsafe conditions, and rapid escalation of abnormal events. This finding has aligned closely with the literature describing industrial IoT as a technical architecture that connects machines, devices, and processes through continuous data exchange, thereby enabling more responsive control and better operational awareness. It has also been strongly compatible with work on Industry 4.0 and logistics integration, which has emphasized visibility, interoperability, and data-rich decision support as core strengths of digitalized industrial systems (Taufek et al., 2016). More specifically, the present results have been in line with studies that have examined safety-oriented Industry 4.0 technologies. Systematic reviews have found that enabling technologies such as IoT, wearables, and cyber-physical systems have increasingly supported safety management by improving the quality and speed of information in industrial environments. Likewise, research on real-time surveillance and hazard detection systems has shown that smart monitoring technologies can identify unsafe events closer to the moment of exposure and thereby support earlier intervention. The present study has supported these insights by showing that respondents have perceived faster hazard identification and stronger incident-prevention responsiveness as some of the highest-rated safety outcomes. At the same time, the current study has added something more than many earlier technology-focused studies, because it has not restricted the analysis to monitoring accuracy or technical feasibility alone. Instead, it has evaluated IoT monitoring as a management-relevant predictor of workplace hazard reduction within a broader organizational model (Shah & Ward, 2007). This has allowed the findings to show that IoT-based monitoring has mattered not only because it has generated data, but because that data has been connected to hazard control processes inside industrial facilities. In this sense, the present research has supported and extended prior work by positioning real-time monitoring not as an auxiliary safety technology, but as a core component of operational safety performance.

Another important discussion point has arisen from the hazard-specific findings, especially the result that machine-related hazards and unsafe process deviations have shown the strongest reduction. This has suggested that the integrated model examined in the study has been especially effective where risk has been closely tied to equipment behavior, process flow, and system-state changes. That pattern has made theoretical and practical sense. Lean Six Sigma has likely improved discipline in how work has been performed, while IoT-based monitoring has increased the speed with which abnormal equipment states and operational deviations have been recognized. Earlier literature has already pointed toward this kind of complementarity (Pech et al., 2021). Studies on occupational health and safety management in companies have shown that effective safety outcomes depend heavily on structured management practices, organizational routines, and the quality of safety systems rather than on isolated acts of compliance alone (Pepper & Spedding, 2010). Research reviewing determinants of safety outcomes across high-risk industries has similarly shown that safety performance is shaped by a mixture of workplace characteristics, climate, management influences, and employee-related factors. In the present study, those broad determinants have become visible in a more specific industrial pattern: the strongest improvements have appeared in hazard categories that have been most susceptible to standardized control and real-time detection. This also fits with work suggesting that safety interventions are most effective when they address hazards through system-level changes to

conditions, tools, and work arrangements rather than relying only on worker vigilance. Therefore, the ranking of hazard categories in this study has carried important practical implications. It has implied that industrial firms have likely derived the greatest safety benefit from integration when hazards have been process-linked, equipment-linked, and time-sensitive (Sakouhi & Nadeau, 2016). At the same time, the somewhat lower means for delayed hazard reporting and chemical exposure have suggested that not all risk domains have responded equally. This has indicated that some hazards may still depend more heavily on reporting culture, specialized controls, or environmental management mechanisms that extend beyond the specific integration model tested here. Thus, while the findings have supported the overall effectiveness of Lean Six Sigma plus IoT monitoring, they have also suggested that sector-specific hazard profiles should remain central in implementation decisions. The practical implication has been that organizations should not only integrate these systems generally, but should align them strategically with the categories of hazard that are most prevalent in their own operational context.

**Figure 10: Proposed Integrated Socio-Technical Model for Future Workplace Hazard Reduction Research**



From a theoretical perspective, the findings have provided strong support for Socio-Technical Systems Theory, which has served as the central theoretical lens of the study. The theory has argued that performance and safety emerge from the interaction of social and technical subsystems rather than from either subsystem alone, and the current findings have reflected that proposition very clearly. The significant interaction term between Lean Six Sigma and IoT-based real-time monitoring has been especially important in this regard because it has shown that the combined use of social-managerial structures and technical-monitoring structures has produced stronger workplace hazard reduction than either variable alone (Singh et al., 2021). This is directly consistent with the socio-technical argument developed by Carayon and colleagues, who described workplace safety as the product of layered interactions among the work system, socio-organizational context, and wider environment. It has also aligned with Sony and Naik’s proposition that Industry 4.0 implementation should be understood and designed through a socio-technical lens because the value of digital technologies depends on their fit with people, culture, processes, and organizational goals (Carayon et al., 2015; Sony & Naik, 2020). The present study has effectively confirmed that same logic in the more specific context of industrial hazard reduction. The findings have suggested that Lean Six Sigma has represented the social-managerial side of system optimization by structuring routines, analysis, and corrective action, while IoT monitoring has represented the technical side by enhancing sensing, visibility, and rapid feedback. The fact that the high Lean Six Sigma–high IoT condition has produced the strongest hazard reduction has further strengthened this interpretation. In comparison with prior studies that have treated lean systems, safety systems, and Industry 4.0 technologies in relatively separate streams, the

current study has shown that the best explanatory power has emerged when those elements have been treated as interacting parts of one system. The theoretical implication has therefore been substantial: workplace hazard reduction in industrial facilities should be interpreted not merely as a consequence of safety culture or digital capability independently, but as an emergent outcome of system alignment. This has advanced the theory in a practical direction by showing how socio-technical coordination can be operationalized and tested quantitatively in an industrial safety context (Knop, 2022).

The limitations of the study, when revisited in light of the discussion, have also clarified how the findings should be interpreted. First, the study has relied on a cross-sectional design, which has allowed the researcher to examine statistically significant associations and predictive relationships, but has not allowed the temporal sequencing of change to be observed directly. Therefore, although the results have strongly supported the hypotheses, they have not fully demonstrated how hazard reduction has evolved over time after the adoption of Lean Six Sigma and IoT-based monitoring. Earlier research has indicated that both process-improvement systems and digital safety systems can produce effects that depend on implementation maturity, organizational learning, and sustained adaptation rather than on one-time adoption alone (Oah et al., 2018). This means that the positive results observed in the present study may represent one stage in a broader developmental process. Second, the research has depended on self-reported perceptions captured through Likert-scale questionnaires. That approach has been appropriate for measuring perceptions of process discipline, technological visibility, and hazard reduction, yet it has also meant that the findings have reflected experienced and perceived improvement rather than directly measured accident frequency, exposure hours, or sensor logs. Prior literature on safety climate and safety management has shown that perceptions are highly consequential and often strongly predictive of safety outcomes, but perceptual measures can still differ from objective incident records in important ways. Third, the case-study-based orientation has improved contextual depth but has also limited generalizability across all industrial sectors. The literature has repeatedly shown that industrial context matters because different sectors face different hazard structures, technological readiness levels, and process complexities (Roberts et al., 2022). Consequently, the effects observed here may not transfer uniformly to every industrial environment. A final limitation has been that the model has focused on two major predictors only. While that has been analytically appropriate for the study title and hypotheses, other factors such as leadership quality, training intensity, maintenance culture, regulatory pressure, and workforce digital literacy may also have influenced hazard reduction. These limitations have not invalidated the findings; rather, they have helped clarify the boundaries within which the present results should be interpreted and applied.

Future research has been the most important next step emerging from this discussion, because the present study has opened a clear pathway for a more advanced explanatory and implementation-oriented research agenda. The strongest future direction would be the development and testing of an Integrated Socio-Technical Hazard Reduction Model in which Lean Six Sigma and IoT-based real-time monitoring remain core antecedents, but additional mediating and moderating variables are introduced to explain how and under what conditions the integration produces better safety outcomes (Vinodkumar & Bhasi, 2010). A particularly promising model would position safety process discipline and real-time hazard visibility as serial mediators between the two core independent variables and workplace hazard reduction, while also testing digital safety capability, leadership commitment, and worker training intensity as moderators. Such a model would allow future researchers to examine whether Lean Six Sigma first strengthens disciplined safety routines, whether IoT first strengthens hazard visibility, and whether the combination then reduces incidents, near misses, exposure time, and unsafe deviations more effectively under conditions of strong leadership and adequate worker digital competence (Shah & Ward, 2007). This proposal has been grounded in earlier literature that has already suggested the importance of socio-technical fit in Industry 4.0 implementation, the role of lean-digital integration in operational performance, and the increasing relevance of Industry 4.0 technologies for safety management (Rossini et al., 2022). A second future direction would be to move from cross-sectional designs to longitudinal and quasi-experimental designs that track implementation before and after system integration using both survey data and objective operational indicators such as accident rates, maintenance downtime, machine alarms, sensor exceptions, and near-miss logs. A third direction

would be sectoral comparison, where the proposed model is tested across chemical processing, heavy manufacturing, warehousing, food production, and energy facilities to determine whether the same interaction pattern holds under different hazard regimes. In practical terms, future studies should therefore move toward a mixed, multi-source, and time-sensitive research design that combines subjective Likert-scale evidence with objective digital traces and safety records. That agenda would not only refine the present study but would also help researchers build a stronger causal, sector-sensitive, and implementation-ready science of integrated industrial hazard reduction.

## **CONCLUSION**

This research has concluded that the integration of Lean Six Sigma and IoT-based real-time monitoring has provided a strong and credible framework for workplace hazard reduction in industrial facilities. The study has been grounded in the understanding that modern industrial safety has required more than routine inspections, policy statements, or reactive incident responses, because hazards in industrial settings have often emerged from unstable processes, equipment abnormalities, weak procedural control, delayed communication, and limited visibility into real-time operating conditions. Within this context, the study has examined Lean Six Sigma as a structured managerial approach for reducing variation, improving process discipline, strengthening root-cause analysis, and promoting continuous improvement, while IoT-based real-time monitoring has been examined as a technological mechanism for sensor-based hazard detection, immediate alerts, ongoing surveillance, and faster response to unsafe conditions. The findings of the study have shown that both variables have made meaningful and statistically significant contributions to workplace hazard reduction, and the integrated effect of both has been stronger than the isolated effect of either one alone. This has indicated that industrial facilities have achieved better safety outcomes when disciplined process improvement has worked together with real-time technological oversight. The study has therefore confirmed that hazard reduction has not been solely a matter of worker caution or regulatory compliance, but has increasingly become a function of how effectively industrial organizations have aligned their managerial systems with their technological systems. In relation to the specific objectives of the research, the study has successfully demonstrated that Lean Six Sigma has improved workplace hazard reduction, that IoT-based real-time monitoring has strengthened safety responsiveness and hazard visibility, and that the interaction between these two has produced a more powerful and comprehensive safety effect. Theoretically, the study has also concluded that Socio-Technical Systems Theory has provided a strong explanatory lens, because the results have shown that the best workplace safety outcomes have emerged where social-managerial structures and technical-monitoring structures have been jointly optimized. Practically, the research has established that integrated safety management has been especially effective in reducing machine-related hazards, process deviations, and other time-sensitive industrial risks. Overall, this study has contributed to industrial safety knowledge by demonstrating that Lean Six Sigma and IoT-based real-time monitoring should not be treated as separate improvement initiatives, but as complementary elements of an integrated safety architecture capable of improving visibility, discipline, responsiveness, and hazard control in industrial facilities. The conclusion of this research has therefore been that workplace hazard reduction in contemporary industrial environments has been most effective when continuous improvement principles and real-time monitoring technologies have been systematically combined within one coordinated operational framework.

## **RECOMMENDATION**

This research has recommended that industrial facilities should adopt an integrated safety-management approach in which Lean Six Sigma and IoT-based real-time monitoring have been deliberately combined as complementary systems for workplace hazard reduction. First, industrial managers should ensure that Lean Six Sigma has not remained limited to productivity improvement or quality control only, but has been extended directly into occupational safety processes such as hazard identification, incident analysis, corrective-action design, root-cause investigation, and safety standardization. This has been important because the findings have shown that structured process discipline has significantly contributed to safer work conditions. Second, organizations should invest in IoT-based real-time monitoring systems such as sensors, connected devices, smart dashboards, automated warning systems, wearable safety tools, and abnormal-event alert mechanisms in order to

improve continuous visibility over industrial hazards. These technologies should be introduced not as isolated technical installations, but as active components of everyday safety operations that have supported earlier detection and faster intervention. Third, industrial organizations should create formal alignment between operational excellence teams and workplace safety teams so that data gathered from real-time monitoring systems have been translated into Lean Six Sigma-based corrective actions and process redesign decisions. This would allow safety issues to be handled systematically rather than reactively. Fourth, management should provide continuous training for managers, engineers, technicians, safety officers, and operational workers so that all relevant personnel have understood both the procedural side of Lean Six Sigma and the practical use of monitoring technologies. Such training should include hazard recognition, data interpretation, response protocols, and continuous-improvement routines linked to safety performance. Fifth, organizations should establish periodic performance-review systems in which workplace hazard data, near misses, machine abnormalities, unsafe process deviations, and safety-rule violations have been tracked and analyzed using both statistical methods and digital monitoring outputs. Sixth, industrial policymakers and regulators should encourage the adoption of integrated digital and process-based safety frameworks by supporting standards, incentives, and compliance guidelines that recognize the value of real-time monitoring linked to continuous improvement. Finally, future implementation efforts within industrial facilities should prioritize the hazard categories that have shown the strongest benefit from integration, especially machine-related risks, process deviations, and operationally dynamic safety threats. In summary, this research has recommended that industrial safety should be managed through an integrated socio-technical strategy where Lean Six Sigma has strengthened discipline, consistency, and corrective action, while IoT-based monitoring has strengthened visibility, speed, and predictive awareness. By adopting such a coordinated approach, industrial facilities would have been better positioned to reduce workplace hazards, improve employee protection, and sustain safer operational performance over time.

#### **LIMITATIONS OF THE STUDY**

This study has been subject to several limitations that should be considered when interpreting its findings. First, the research has employed a quantitative, cross-sectional, case-study-based design, which has been appropriate for examining the relationships among Lean Six Sigma, IoT-based real-time monitoring, and workplace hazard reduction at a specific point in time, but this design has not fully captured how these relationships may have evolved over longer implementation periods. Since workplace safety improvement, process standardization, and technological adaptation have often developed gradually, a cross-sectional approach has not revealed the long-term progression of hazard reduction after the introduction of integrated systems. Second, the study has relied on self-reported questionnaire responses measured through a five-point Likert scale. Although this has allowed perceptions, experiences, and organizational practices to be quantified, the data have reflected respondents' judgments rather than direct observational measures such as sensor logs, incident databases, or longitudinal safety records. As a result, the findings have represented perceived workplace hazard reduction rather than exclusively objective hazard statistics. Third, the study has focused on selected industrial facilities within a case-study context, which has improved contextual relevance but has also limited the extent to which the findings may be generalized to all industrial sectors, all geographical regions, or all operational environments. Different industries have often faced different hazard structures, regulatory pressures, levels of digital readiness, maintenance cultures, and workforce skill profiles, which means that the strength of integration effects may vary across settings. Fourth, the study has concentrated on two major explanatory variables only, namely Lean Six Sigma and IoT-based real-time monitoring. While this has been consistent with the research title and objectives, other potentially influential variables such as safety leadership, workforce digital literacy, maintenance capability, employee engagement, organizational culture, training quality, and regulatory enforcement have not been directly modeled. Fifth, the interaction model used in the study has demonstrated combined influence, but it has not fully explored more complex mediation or moderation pathways that may explain how hazard reduction has occurred in practice. Finally, the pilot-tested and reliable questionnaire has still been limited by the wording and scope of the selected items, which means that some nuanced aspects of industrial safety practice may not have been fully represented.

These limitations have not invalidated the results of the study; rather, they have defined the boundaries within which the findings should be understood. Therefore, the conclusions of this research should be applied with awareness that the evidence has been robust within the selected context, yet not exhaustive of every variable, every industrial setting, or every time-based dimension relevant to integrated workplace hazard reduction.

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