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# Artificial Intelligence and Smart Technologies in Safety Management: A Comprehensive Analysis Across Multiple Industries

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**Abstract:** The integration of Artificial Intelligence (AI) and smart technologies into safety management is a pivotal aspect of the Fourth Industrial Revolution or Industry 4.0. This study conducts a systematic literature review to identify and analyze how AI and smart technologies enhance safety management across various sectors within the Safety 4.0 paradigm. Focusing on peer-reviewed journal articles that explicitly mention "Smart", "AI", or "Artificial Intelligence" in their titles, the research examines key safety management factors, such as accident prevention, risk management, real-time monitoring, and ethical implementation, across sectors, including construction, industrial safety, disaster and public safety, transport and logistics, energy and power, health, smart home and living, and other diverse industries. AI-driven solutions, such as predictive analytics, machine learning algorithms, IoT sensor integration, and digital twin models, are shown to proactively identify and mitigate potential hazards, optimize energy consumption, and enhance operational efficiency. For instance, in the energy and power sector, intelligent gas meters and automated fire suppression systems manage gas-related risks effectively, while in the health sector, AI-powered health monitoring devices and mental health support applications improve patient and worker safety. The analysis reveals a significant trend towards shifting from reactive to proactive safety management, facilitated by the convergence of AI with IoT and Big Data analytics. Additionally, ethical considerations and data privacy emerge as critical challenges in the adoption of AI technologies. The study highlights the transformative role of AI in enhancing safety protocols, reducing accident rates, and improving overall safety outcomes across industries. It underscores the need for standardized protocols, robust AI governance frameworks, and interdisciplinary research to address existing challenges and maximize the benefits of AI in safety management. Future research directions include developing explainable AI models, enhancing human–AI collaboration, and fostering global standardization to ensure the responsible and effective implementation of AI-driven safety solutions.

**Keywords:** artificial intelligence; safety management; Safety 4.0; Industry 4.0; smart technologies; proactive safety

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**Citation:** Park, J.; Kang, D. Artificial Intelligence and Smart Technologies in Safety Management: A Comprehensive Analysis Across Multiple Industries. *Appl. Sci.* **2024**, *14*, 11934. https://doi.org/10.3390/app142411934

Academic Editor: Mirco Peron

Received: 21 October 2024
Revised: 7 December 2024
Accepted: 12 December 2024
Published: 20 December 2024



## 1. Introduction

The Industrial Revolution has fundamentally transformed human lifestyles and production methods. The First Industrial Revolution enabled mechanized production through the invention of the steam engine, and the Second Industrial Revolution established mass production systems with the introduction of electricity. The Third Industrial Revolution saw the advancement of information technology, leading to automation and informatization. Currently, we are entering the era of the Fourth Industrial Revolution, or Industry 4.0, characterized by the convergence of advanced technologies such as Cyber-Physical Systems (CPS), the Internet of Things (IoT), Big Data, and Artificial Intelligence (AI) [1,2].

Industry 4.0 maximizes the efficiency and flexibility of production systems, enabling customized mass production and enhancing competitiveness through the efficient use of resources and optimization of production processes [1,2]. However, these technological innovations drastically change existing industrial structures and work environments, potentially causing new types of risks and safety issues [3,4]. For example, the adoption of CPS and IoT increases cybersecurity risks, and unexpected accidents may occur in the interactions between automated systems and human workers [2,3].

In this context, Safety 4.0 has emerged as a new safety management paradigm within the Industry 4.0 environment [5,6]. Safety 4.0 aims to prevent accidents and enhance safety awareness by leveraging advanced technologies and integrating the core technologies of Industry 4.0 into safety management to simultaneously improve safety and productivity [3,6]. Alcácer and Cruz-Machado [1] analyzed the impact of Industry 4.0's core technologies on manufacturing systems and suggested that these technologies could also be applied to safety management.

AI has emerged as a key element in implementing Safety 4.0, enabling prediction and real-time response through its ability to analyze vast amounts of data and recognize patterns [2,7]. For instance, machine learning algorithms can detect anomalies in equipment in advance to prevent breakdowns, and deep learning-based image analysis technologies can monitor hazardous factors in the work environment in real time [2,8]. Chen et al. [8] demonstrated the application of deep learning models for real-time safety monitoring, such as detecting safety helmet violations in engineering environments. The application of these AI technologies can significantly contribute to protecting workers' safety and reducing accident rates.

Moreover, the application of human-centered technology is emphasized as an important factor in Safety 4.0 [5,9]. Romero et al. [5] proposed the concept of Operator 4.0, aiming for human–machine symbiosis by enhancing workers' capabilities and safety through advanced technologies. Kaasinen et al. [9] elaborated on solutions like wearable devices, Augmented Reality (AR), and collaborative robotics to empower and engage industrial workers, ultimately improving operational safety and productivity.

However, several challenges exist in implementing Safety 4.0 [6]. Martinetti et al. [6] discussed the applications and challenges of Safety 4.0, pointing out obstacles such as data security concerns, lack of standardization, and organizational cultural changes. Additionally, Kitchenham and Charters [10] emphasized the importance of systematic reviews to synthesize fragmented research and provide comprehensive insights, particularly in fields like safety management, where interdisciplinary approaches are critical. This fragmentation leads to redundant studies and overlooks critical areas, hindering effective technology adoption.

Therefore, to maximize the effectiveness of AI utilization in safety management during the Safety 4.0 era, a systematic analysis of existing studies is necessary. A systematic literature review is essential to identify current research trends, application areas, and technological limitations and to suggest future research directions and practical application strategies [4,10]. Through this, we can prevent research duplication, promote efficient resource utilization, and proactively recognize and strategize responses to technical, organizational, and ethical issues that may arise when adopting AI technologies [7].

The purpose of this study is to systematically identify and analyze how Artificial Intelligence (AI) and smart technologies are currently utilized to enhance safety management factors across various industries within the Safety 4.0 paradigm. Through a comprehensive literature review focused on studies explicitly mentioning "Smart", "AI", or "Artificial Intelligence" in their titles, we aim to achieve the following:

- Examine the specific applications of AI and smart technologies in safety management, including the technologies used, algorithms implemented, and the contexts in which they are applied.
- Identify patterns, trends, and insights from the current body of research that can inform future developments and practical implementations in safety management.

By conducting this in-depth analysis, we seek to provide a comprehensive understanding of the role of AI and smart technologies in transforming safety management practices.

## 2. Materials and Methods

### *2.1. Methodology*

This study conducted a systematic literature review to identify and analyze the application of Artificial Intelligence (AI) and smart technologies in safety management across various industries within the Safety 4.0 paradigm. To enhance focus and relevance, the literature search was performed exclusively based on article titles, as title-based searches reduce the number of retrieved studies while capturing research explicitly addressing AI and smart technologies in the context of safety management.

**The Literature Search Strategy**

The search was conducted using the following databases:

- IEEE Xplore.
- ScienceDirect.
- Google Scholar.

The search strategy applied the following keywords:
((safety management) AND ((smart) OR (AI) OR (artificial intelligence))).

**Inclusion Criteria**

- Peer-reviewed journal articles published up to 16 July 2024.
- Articles explicitly mentioning "Safety management" and "Smart", "AI", or "Artificial Intelligence" in their titles.

**Exclusion Criteria**

- Conference proceedings, unpublished research papers, theses, dissertations, newspapers, and books were excluded to ensure the inclusion of high-quality journal articles.
- Studies not explicitly mentioning the key terms in their titles were excluded to maintain relevance to the research objectives.

### *2.2. Study Selection Process*

The systematic literature review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a transparent and methodical selection process. The study selection steps are summarized as follows:

Initial Identification (N = 187):

The initial search across databases (IEEE Xplore, ScienceDirect, Google Scholar) identified a total of 187 studies. For ScienceDirect, the search was conducted in three separate queries—(safety management) AND (Smart), (safety management) AND (AI), and (safety management) AND (Artificial Intelligence)—due to search limitations, and the results were integrated for analysis. The search was restricted to titles only, as keyword-based searches yielded an unmanageable number of results, making the process impractical within the study's timeframe. However, this approach excluded searches in the Web of Science database, as it did not return results under the title-only search constraint. These studies were retrieved based on their relevance to the research keywords ((safety management) AND ((Smart) OR (AI) OR (Artificial Intelligence))).

Step 1: Duplicate Removal (Excluded: N = 37):

Studies with identical or overlapping content were excluded. After this step, 146 unique studies remained for further screening.

Step 2: Title and Abstract Screening (Excluded: N = 59):

A comprehensive screening of titles and abstracts was conducted, excluding the following:

- Review articles.
- Conference proceedings.

This step ensured that only original peer-reviewed journal articles focusing on the application of AI and smart technologies in safety management were retained. A total of 87 studies passed this phase.

Step 3: Full-Text Screening (Excluded: N = 21):

The full texts of the 87 selected studies were reviewed. Studies were excluded if they exhibited the following:

- Full papers were inaccessible or unavailable.
- After this stage, 66 studies were finalized for inclusion in the systematic review.

Final Inclusion (N = 66):

The 65 studies selected through this rigorous process were included in the final analysis and categorization. These studies form the basis of the insights and findings presented in this review.

This systematic review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The PRISMA flow diagram (Figure 1) summarizes the study identification, screening, eligibility, and inclusion process. This rigorous approach identified recurring research themes and methodologies, focusing on the integration of AI and smart technologies in safety management across diverse sectors. The findings are synthesized into detailed tables, providing a clear overview of how advanced technologies are transforming safety management practices. The final dataset includes 65 studies, categorized into eight industry sectors: construction, industrial safety, disaster and public safety, transport and logistics, energy and power, health, smart home and living, and other sectors.

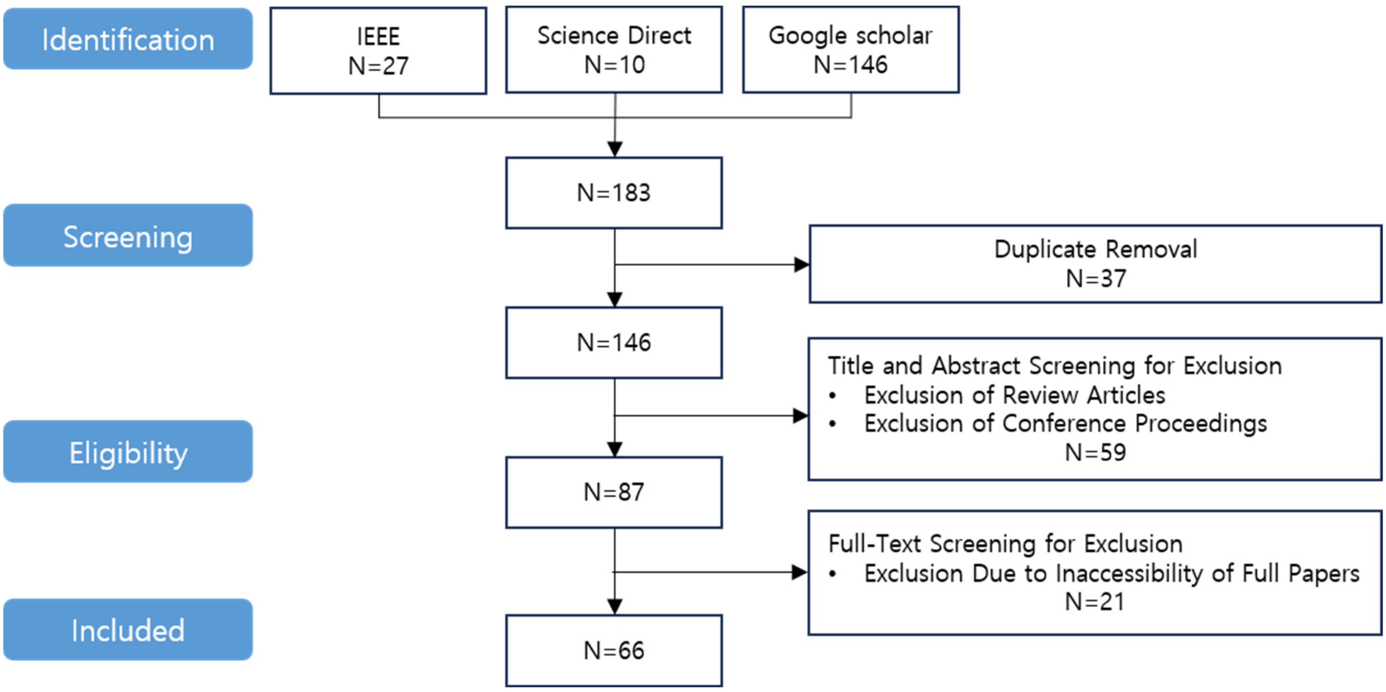


**Figure 1.** Systematic selection process of AI and smart technology applications in safety management.

## 3. Results

### *3.1. Analysis of Methodological Characteristics of the Selected Literature*

The systematic literature review identified 65 relevant research methods from the selected studies. These methodologies were categorized into four main safety management factors across eight industry sectors, ensuring a coherent and logical grouping of research approaches.

Categorization Across Sectors: The selected studies were categorized into the following industry sectors, each addressing specific safety management factors:

1. Construction sector.
2. Industrial safety sector.
3. Disaster and public safety sector.
4. Transport and logistics sector.
5. Energy and power sector.
6. Health sector.
7. Smart home and living sector.
8. Other sectors.

Safety Management Factors: Each sector addressed one or more of the following safety management factors:

- Accident prevention and risk management.
- Workplace and facility safety management.
- Quality assurance and reliability management.
- System-based safety enhancement.

Key Findings:

- Accident prevention and risk management: Predominantly involved AI-driven predictive analytics and sensor-based monitoring systems.
- Workplace and facility safety management: Focused on real-time surveillance using IoT sensors and computer vision technologies.
- Quality assurance and reliability management: Utilized anomaly detection algorithms and ISO/IEC standards to ensure product and process reliability.
- System-based safety enhancement: Emphasized AI-driven automation, smart control systems, and digital twin models to optimize operations and reduce human risk exposure.

Prevalent Themes and Technologies:

- Machine learning and predictive modeling: Widely used for risk prediction and anomaly detection.
- IoT and sensor networks: Essential for real-time data collection and monitoring.
- Digital twin models: Facilitated simulation and assessment of safety scenarios.
- Human-centric technologies: Enhanced worker safety and efficiency through Augmented Reality and wearable devices.

The analysis revealed a significant trend towards integrating AI with IoT and Big Data to shift safety management from reactive to proactive approaches.

Table 1 categorizes the selected studies into eight distinct industry sectors: construction, industrial safety, disaster and public safety, transport and logistics, energy and power, health, smart home and living, and other sectors, highlighting their focus on specific safety management factors.

**Table 1.** Categorization of selected studies across industry sectors.

| Sector | Frequency | First Author (Year) |
|---|---|---|
| Construction | 15 | Cho, et al. (2012) [11], Park, et al. (2013) [12], Seo (2019) [13], Kamarudin, et al. (2020) [14], Jiang, et al. (2021) [15], Zhang, et al. (2021) [16], Kasim, et al. (2021) [17], Getuli, et al. (2022) [18], Lee, et al. (2023) [19], Lee, et al. (2023) [20], Okonkwo, et al. (2023) [21], Qian, et al. (2023) [22], Rane, et al. (2023) [23], Kim, et al. (2024) [24], Fang, et al. (2024) [25] |
| Industrial Safety | 15 | Oh, et al. (2011) [26], Park, et al. (2012) [27], Teimourikia, et al. (2016) [28], Bieder, et al. (2018) [29], Wang, et al. (2019) [30], Jeong, et al. (2019) [31], Eom, et al. (2020) [32], Zhao, et al. (2020) [33], Yi, et al. (2020) [34], Abainza, et al. (2020) [35], Selvik (2021) [36], Ansaldi, et al. (2022) [37], Huang, et al. (2022) [38], Lyu, et al. (2022) [39], Tiikkaja, et al. (2024) [40] |

**Table 1.** *Cont.*

| Sector | Frequency | First Author (Year) |
|---|---|---|
| Disaster and Public Safety | 11 | Liu, et al. (2017) [41], Kang, et al. (2018) [42], Pradhan, et al. (2018) [43], Kim, et al. (2019) [44], Seo, et al. (2020) [45], Zhao, et al. (2023) [46], Almatared, et al. (2023) [47], Li, et al. (2023) [48], Qian (2023) [49], Park, et al. (2023) [50], Zhang, et al. (2024) [51] |
| Transport and Logistics | 8 | Lee, et al. (2010) [52], Lee, et al. (2012) [53], Ku, et al. (2013) [54], Alsarhan, et al. (2018) [55], Sundaramoorthy, et al. (2018) [56], Łosiewicz (2019) [57], Kaul, et al. (2022) [58], Lee, et al. (2024) [59] |
| Energy and Power | 5 | Park, et al. (2011) [60], Oh, et al. (2012) [61], Park, et al. (2013) [62], Tan, et al. (2017) [63], Rahman, et al. (2019) [64] |
| Health | 4 | Lee, et al. (2022) [65], Waqar, et al. (2023) [66], Tang, et al. (2024) [67], Ćosić, et al. (2024) [68] |
| Smart Home and Living | 3 | Huang, et al. (2016) [69], Jeong, et al. (2017) [70], Chang, et al. (2020) [71] |
| Other | 5 | Kim, et al. (2014) [72], Kim, et al. (2015) [73], Stoitsis, et al. (2023) [74], Lee, et al. (2024) [75], Xiao, et al. (2024) [76] |

### *3.2. Analysis of AI and Smart Technology Applications Across Industry Sectors*

The selected studies were systematically analyzed and categorized into eight distinct industry sectors to understand the specific applications of AI and smart technologies in safety management. This sector-wise classification provides a detailed overview of how different industries leverage advanced technologies to enhance safety protocols and mitigate risks.

#### 3.2.1. Integration of AI and Smart Technologies in Safety Management for the Construction Sector

Recent advancements in the construction industry have emphasized the integration of Artificial Intelligence (AI) and smart technologies to enhance safety management. AI-driven solutions address various safety management factors, such as real-time hazard detection, predictive analytics, and enhanced training. For instance, AI-powered smart safety management systems utilize Internet of Things (IoT) sensors, BLE Beacons, and cloud computing to monitor safety data in real time, thereby improving decision-making processes. AI algorithms are employed for accident prevention by analyzing patterns to predict potential hazards, while computer vision detects unsafe behaviors through automated image recognition. Additionally, AI-enhanced Virtual Reality (VR) and Augmented Reality (AR) technologies provide immersive training environments, improving hazard recognition and response in high-risk areas like tunnels.

Moreover, innovative approaches like QR code-based safety inspections are augmented with AI analytics, enabling efficient equipment checks via mobile applications. Cyber-Physical Systems (CPSs) integrated with AI synchronize risk data between virtual and physical construction sites, allowing real-time hazard management and control. The development of IoT helmets equipped with sensors, CCTV, and GPS technologies further enhances continuous safety monitoring. Case studies and field experiments have validated the effectiveness of these smart systems in complex and high-risk environments, such as tunnels, by leveraging AI-based data analysis and real-time monitoring. These applications demonstrate how AI and smart technologies are transforming safety practices in the construction sector, leading to safer work environments and reduced accident rates. These applications demonstrate how AI and smart technologies are transforming safety practices in the construction sector, leading to safer work environments and reduced accident rates. Table 2 shows AI and smart technology research methods for safety management factors in the construction sector. By explicitly incorporating AI-related content into our analysis, we address the critical role of AI in enhancing safety management factors within the industry.

**Table 2.** AI and smart technology research methods for safety management factors in the construction sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Numbers |
|---|---|---|
| **Digital Technology and Smart Safety Management System (SMS)** | - Developed safety apps using smartphones and EPS32 with Bluetooth and beacons.<br>- Utilized web technologies (CSS, HTML, JavaScript) for hybrid applications.<br>- Implemented BLE Beacon-based detection and noise filtering algorithms.<br>- Integrated Arduino and multiple sensors for smart systems.<br>- Created IoT helmets with sensors, CCTV, and GPS.<br>- Digitalized safety management through detailed BIM models.<br>- Combined AI models with machine vision for hazard detection.<br>- Established real-time monitoring using video and image data. | [11,12,18,21] |
| **Accident Prevention and Response** | - Developed AI-based hazard detection systems.<br>- Created real-time emergency detection using AI and sensors.<br>- Analyzed construction equipment accident data for prevention.<br>- Utilized drones for continuous safety monitoring at construction sites. | [11,13,17,24] |
| **Complexity and High-risk Working Environment** | - Conducted case studies on safety in tunnels and high-risk areas.<br>- Performed field experiments to validate smart construction systems.<br>- Applied AI-based data analysis for safety management in complex environments. | [14,19,20,24] |
| **Data-driven Safety Management** | - Developed data-driven safety algorithms and evaluated their reliability.<br>- Established real-time monitoring systems with video and image data.<br>- Conducted simulations using power grid and load data to test safety strategies. | [14,16,22,25] |
| **IoT and AI-based Safety Management** | - Created IoT-based safety devices (fire detection, location monitoring, etc.).<br>- Implemented BLE Beacon for real-time worker tracking.<br>- Integrated machine vision with AI for enhanced hazard detection.<br>- Developed IoT helmets with integrated sensors, CCTV, and GPS. | [16,17,22] |
| **BIM and AI Integration** | - Combined BIM models with AI algorithms for safety management.<br>- Implemented VR-based safety training using BIM-VR protocols.<br>- Conducted literature reviews and expert interviews on BIM and AI integration.<br>- Proposed an integrated safety management framework based on BIM and AI. | [16,23] |
| **Tunnel and Complex Environment Safety Management** | - Developed integrated safety systems with Bluetooth scanners and environmental sensors.<br>- Tested and validated systems in actual tunnel construction sites.<br>- Applied AI-driven data analysis for tunnel safety management.<br>- Conducted case studies on safety practices in tunnels. | [19,20] |
| **QR Code-based Safety Inspection** | - Developed AI-based QR code recognition systems.<br>- Created smartphone applications for QR code safety inspections and management. | [15] |
| **Elderly Worker Accident Prevention** | - Used AI to analyze data and develop accident prevention measures for elderly workers.<br>- Conducted interviews and surveys to gather expert insights on safety management for elderly workers. | [75] |
| **Smart Emergency Detection System** | - Developed real-time emergency detection systems using AI and sensors.<br>- Applied and validated emergency detection systems in construction sites. | [73] |

### 3.2.2. Integration of AI and Smart Technologies in Safety Management for the Industrial Safety Sector

In the industrial safety sector, the integration of Artificial Intelligence (AI) and smart technologies is transforming safety management practices by addressing key factors such as technology-centered approaches, data-driven decision-making, and real-time monitoring. The reviewed studies highlight the use of AI algorithms, machine learning, and IoT devices to enhance safety outcomes. For example, AI-powered predictive analytics analyze vast amounts of safety incident data, enabling the identification of risk factors in real time and improving Safety Performance Indicators (SPIs). Smart environments equipped with AI and IoT facilitate real-time monitoring, allowing for immediate responses to hazards and enhancing overall safety efficiency.

Moreover, the implementation of frameworks like PIPSC/CMF integrates indoor GIS with Bluetooth and RFID-based positioning technologies to support comprehensive fire detection systems and command platforms. AI-powered disaster response platforms combine historical disaster data, intelligent CCTV, sensors, satellite information, and social network data to support real-time emergency management. Smart street lighting systems, designed with GSM, GPS, cameras, LED lighting, and emergency buttons, have been prototyped using Arduino and ATMEGA 32 microprocessors to improve urban safety.

AI contributes to efficiency and cost reduction by automating safety processes and providing quantitative metrics-based evaluations through Big Data Analysis (BD Analysis) and digital twin simulations. These technological advancements support a cultural shift towards proactive safety management, emphasizing teamwork and continuous improvement. By leveraging AI and smart technologies, organizations can transition from traditional reactive approaches to predictive and preventive strategies, resulting in reduced workplace accidents and improved working conditions. Table 3 presents AI and smart technology research methods for safety management factors in the industrial sector. The convergence of these technologies in safety management demonstrates a paradigm shift across various industries, showcasing the critical role of AI in enhancing industrial safety practices.

**Table 3.** AI and smart technology research methods for safety management factors in the industrial safety sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Technology-centered Approach** | - Designed the PIPSC/CMF framework integrating indoor GIS with positioning and navigation technologies.<br>- Combined Bluetooth and RFID passive labels for indoor positioning and fire detection systems.<br>- Implemented digital twin frameworks for tunnel fire safety management with AIoT<br>-based fire detection systems.- Developed smart street lighting systems using GSM, GPS, cameras, LED lighting, and emergency buttons with Arduino and ATMEGA 32 microprocessors. | [32,33,36,39,40] |
| **Data-driven Decision-making** | - Utilized data mining and statistical analysis to analyze fire patterns and causes.<br>- Conducted Big Data Analysis (BD Analysis) to identify fire hotspots and simulate fire scenarios.<br>- Employed AI algorithms for predictive maintenance and accident prevention by analyzing operational data to forecast potential equipment failures. | [26,27,30,32,35] |
| **Smart Environments and Real-time Monitoring** | - Developed real-time AI-based disaster response platforms integrating historical data, intelligent CCTV, sensors, satellites, and social network information.<br>- Implemented IoT sensors for continuous monitoring and real-time data collection in smart buildings.<br>- Created smart street lighting systems with integrated emergency response features. | [26,29,34,35] |
| **Cultural Approach and Teamwork** | - Conducted expert interviews and surveys to gather insights on safety management strategies.<br>- Developed smart mobile applications supporting real-time safety notices, checklist creation, and daily safety activity management.<br>- Fostered teamwork through AI-driven safety protocols and communication tools. | [28,39,40] |

**Table 3.** *Cont.*

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Efficiency and Cost Reduction** | - Designed smart street lighting system prototypes using cost-effective microprocessors.<br>- Integrated IoT and knowledge management (KM) with sustainable development (SD) principles to form robust safety frameworks.<br>- Developed AI-based resource optimization systems for efficient safety management. | [34–36] |
| **Quantitative Metrics-based Evaluation** | - Established quantitative metrics through Big Data Analysis for evaluating fire safety systems.<br>- Utilized digital twin simulations to analyze safety scenarios and optimize response strategies.<br>- Applied quantitative metrics in BIM digital twin models for real-time safety assessments. | [27,28,35] |

#### 3.2.3. Integration of AI and Smart Technologies in Safety Management for Disaster and Public Safety Sector

In the disaster and public safety sector, key safety management factors such as urbanization and public safety management, disaster and fire safety management, hazardous workplaces and industrial safety, and the integration of smart technologies with public safety are being significantly enhanced through the integration of Artificial Intelligence (AI) and smart technologies. AI-driven solutions address these critical factors by leveraging advanced frameworks, real-time monitoring systems, and predictive analytics. For instance, the design of the PIPSC/CMF framework integrates indoor GIS with Bluetooth and RFID-based positioning technologies to develop comprehensive fire detection systems and command platforms. Additionally, AI-powered disaster response platforms combine historical disaster data, intelligent CCTV, sensors, satellite information, and social network data to support real-time emergency management.

Smart street lighting systems, designed with GSM, GPS, cameras, LED lighting, and emergency buttons, are prototyped using Arduino and ATMEGA 32 microprocessors to enhance urban safety. These systems not only provide illumination but also integrate crime statistics analysis and case studies to optimize safety measures. Furthermore, the implementation of safety tags equipped with accelerometer sensors detects workers' immobilization, while command unit terminals use two-way wireless communication to issue escape commands during emergencies. Centralized control servers are developed to manage resources efficiently across multiple organizations. AI governance frameworks ensure the responsible use of AI systems in smart cities, protecting public safety while adhering to regulatory standards. Data mining and statistical analysis techniques are utilized to analyze fire occurrence patterns and causes, while Big Data Analysis (BD Analysis) identifies temporal and spatial fire hotspots and simulates fire scenarios to optimize firefighting and evacuation strategies.

These applications demonstrate how AI and smart technologies address critical safety challenges in the disaster and public safety sector, leading to improved operational efficiency and enhanced safety outcomes. Table 4 summarizes AI and smart technology research methods for safety management factors in the disaster and public safety sector. By explicitly incorporating AI-related methodologies into safety management, the disaster and public safety sector can achieve significant improvements in safety protocols, emergency response effectiveness, and overall public safety.

**Table 4.** AI and smart technology research methods for safety management factors in the disaster and public safety sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Urbanization and Public Safety Management** | - Designed the PIPSC/CMF framework integrating indoor GIS with Bluetooth and RFID-based positioning technologies.<br>- Implemented smart street lighting systems with GSM, GPS, cameras, LED lighting, and emergency buttons using Arduino and ATMEGA 32 microprocessors.<br>- Conducted crime statistics analysis and case studies to optimize urban safety measures. | [41,46,48] |
| **Disaster and Fire Safety Management** | - Developed AI-powered disaster response platforms integrating historical data, intelligent CCTV, sensors, satellite information, and social network data.<br>- Utilized data mining and BD Analysis to identify fire hotspots and simulate fire scenarios.<br>- Implemented AIoT-based fire detection systems within digital twin frameworks for real-time safety assessments. | [47,49,51] |
| **Hazardous Workplaces and Industrial Safety** | - Employed AI algorithms for monitoring hazardous conditions and predicting potential workplace hazards.<br>- Integrated safety tags with accelerometer sensors and developed command unit terminals for real-time hazard communication.<br>- Built centralized control servers to manage safety data across multiple organizations. | [44,45] |
| **Integration of Smart Technologies and Public Safety** | - Utilized IoT sensors and AI governance frameworks to enhance public safety in smart cities.<br>- Developed smart mobile applications for real-time safety notices, checklist creation, and daily safety activity management.<br>- Implemented AI-based monitoring systems for immersive fire monitoring and emergency response. | [42,43,50] |

#### 3.2.4. Integration of AI and Smart Technologies in Safety Management for the Transport and Logistics Sector

In the transport and logistics sector, key safety management factors such as traffic accident prevention and collision avoidance, railway safety and worker protection, maritime and industrial site safety management, and public transport safety management are being significantly enhanced through the integration of Artificial Intelligence (AI) and smart technologies. AI-based predictive models and machine learning algorithms analyze real-time traffic data, vehicle behavior, and environmental conditions to predict and prevent traffic accidents. These technologies enable proactive traffic management and collision avoidance systems in vehicles, reducing collision risks and improving overall road safety.

For railway safety, AI algorithms process data from IoT sensors to detect equipment anomalies and predict maintenance needs, ensuring system reliability and preventing accidents caused by equipment failure. Additionally, literature reviews and accident statistics analyses identify common accident types among railway workers, informing the design of safety management systems that utilize smartphone GPS technologies. The effectiveness of Safety Management Systems (SMSs) is further evaluated through case studies, such as the Lac-Mégantic accident, and comparative analyses of regulatory models.

In maritime safety, AI-driven navigation systems and autonomous vessels utilize AI to prevent collisions at sea. Predictive analytics support industrial site safety by automating the monitoring of hazardous conditions. Public transport safety management is enhanced by AI-enhanced surveillance systems employing facial recognition and behavioral analysis to detect suspicious activities. Furthermore, Big Data analytics optimize safety protocols and emergency responses, ensuring timely and effective measures in public transportation environments.

These applications demonstrate how AI and smart technologies address critical safety challenges in the transport and logistics sector, leading to improved operational efficiency and enhanced safety outcomes. Table 5 presents AI and smart technology research methods for safety management factors in the transport and logistics sector.

**Table 5.** AI and smart technology research methods for safety management factors in the transport and logistics sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| Traffic Accident Prevention and Collision Avoidance | - AI-based predictive models and machine learning algorithms for real-time traffic analysis and collision avoidance.<br>- Utilized CNNs, ARIMA, and LSTM for traffic flow prediction and congestion warnings.<br>- Implemented Steering Control Collision Avoidance Systems (SCCASs). | [53,55,58] |
| Railway Safety and Worker Protection | - Designed PIPSC/CMF framework integrating indoor GIS with Bluetooth and RFID positioning.<br>- Analyzed railway accident data through literature reviews and statistics.<br>- Developed and evaluated safety management systems using smartphone GPS and case studies like Lac-Mégantic.<br>- Implemented OSGi-based monitoring, facial recognition, WMN, and integrated sensors.<br>- Created intelligent bridge management and AI-based control systems. | [52,54] |
| Maritime and Industrial Site Safety Management | - Developed AI-driven navigation and autonomous vessels to prevent maritime collisions.<br>- Employed predictive analytics for monitoring hazardous conditions.<br>- Implemented AI-powered fire detection and digital twin models for real-time safety assessments. | [57,59] |
| Public Transport Safety Management | - Enhanced surveillance with AI-based facial recognition and behavioral analysis.<br>- Utilized Big Data analytics to optimize safety protocols and emergency responses.<br>- Developed AI-powered predictive models for public transport safety.<br>- Implemented AI-based real-time monitoring systems. | [56] |

#### 3.2.5. Integration of AI and Smart Technologies in Safety Management for the Energy and Power Sector

In the energy and power sector, key safety management factors such as gas safety and risk management, power grid and energy management, real-time monitoring and alert systems, urban gas facility risk management, and resource consumption and energy efficiency management are significantly enhanced through the integration of Artificial Intelligence (AI) and smart technologies. AI-driven solutions include the development of intelligent gas meters and automated fire suppression systems, effectively managing gas-related risks. Wireless modularization and networking technologies enable robust real-time monitoring and alert systems, ensuring immediate responses to hazards. Additionally, web-based safety management systems support data-driven decision-making by integrating comprehensive safety data for analysis.

Smart meters are crucial for power grid management, automatically controlling power supply based on appliance priority, detecting faulty cabling, and identifying recalled appliances to ensure safety. Resource consumption and energy efficiency are optimized through low-cost appliance control solutions using advanced power distribution systems. Urban gas facility risk management is enhanced by Smart Home Gas Safety Management Systems (S-GSMSs), which are validated through scenario-based assessments and system tests.

AI governance frameworks ensure responsible AI use in smart cities, protecting public safety while complying with regulations. Data mining and Big Data Analysis (BD Analysis) identify fire hotspots and simulate scenarios to optimize firefighting and evacuation strategies. Digital twin models provide real-time safety scenario simulations, offering immersive fire monitoring and enhancing overall safety management.

These applications demonstrate how AI and smart technologies address critical safety challenges in the energy and power sector, leading to improved operational efficiency, enhanced safety outcomes, and sustainable energy management. Table 6 provides AI and smart technology research methods for safety management factors in the energy and power sector. Incorporating AI methodologies into safety management enables significant advancements in safety protocols, emergency response, and energy efficiency.

**Table 6.** AI and smart technology research methods for safety management factors in the energy and power sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Numbers |
| --- | --- | --- |
| **Gas Safety and Risk Management** | - Developed intelligent gas meters for accurate monitoring.<br>- Implemented automated fire suppression systems.<br>- Designed Smart Home Gas Safety Management Systems (S-GSMSs) with scenario-based evaluations.<br>- Integrated Bluetooth and RFID-based positioning for comprehensive gas safety systems. | [60,62] |
| **Power Grid and Energy Management** | - Proposed low-cost solutions for appliance ON/OFF control using new power distribution systems.<br>- Utilized smart meters to automatically adjust power based on appliance priority.<br>- Developed AI-based resource optimization systems for efficient energy management.<br>- Implemented Battery Management Systems (BMSs) with AI-driven protection using MATLAB Simulink. | [63] |
| **Real-time Monitoring and Alert Systems** | - Employed wireless modularization and networking for robust real-time monitoring.<br>- Developed web-based safety management systems for data-driven decision-making.<br>- Utilized AI-based monitoring systems, including time-safety metrics (TTBU) and real-time safety assessment using Extreme Learning Machines (ELMs).<br>- Implemented remote visualization and intelligent alarm systems for immediate hazard detection. | [62] |
| **Urban Gas Facility Risk Management** | - Designed and prototyped smart street lighting systems with integrated safety features using GSM, GPS, cameras, LED lighting, and emergency buttons.<br>- Conducted crime statistics analysis and case studies to optimize urban gas facility safety measures.<br>- Utilized digital twin models for immersive fire monitoring and real-time safety assessments. | [61] |
| **Resource Consumption and Energy Efficiency Management** | - Developed AI-powered predictive models to analyze and optimize resource consumption.<br>- Implemented energy-efficient solutions through smart meters and automated power control systems.<br>- Utilized digital twin simulations to evaluate and enhance energy efficiency strategies.- Integrated sustainable development (SD) principles with IoT and knowledge management (KM) for robust energy management frameworks. | [64] |

#### 3.2.6. Integration of AI and Smart Technologies in Safety Management for the Health Sector

In the health sector, AI and smart technologies significantly enhance safety management by addressing critical factors such as occupational risk management and prevention, smart health monitoring and prevention, mental health management and prevention, and technological integration with ethical implementation. For occupational risk management and prevention, AI-based predictive analytics and machine learning algorithms analyze data on healthcare workers' exposure to risks like infectious diseases and ergonomic hazards. This enables proactive measures to prevent workplace accidents and improve safety protocols. In smart health monitoring and prevention, wearable devices equipped with AI and IoT sensors collect real-time physiological data such as heart rate and blood pressure. AI algorithms process these data to detect anomalies, predict health events, and provide personalized recommendations, enhancing patient safety through early detection and timely intervention. Mental health management and prevention are addressed through AI chatbots and applications using natural language processing to offer mental health support, assess emotional states, and provide immediate assistance. Machine learning models identify signs of mental health issues, facilitating timely interventions and access to professional help. Lastly, technological integration and ethical implementation ensure the responsible use of AI in healthcare. AI ethics frameworks and secure data management practices protect patient privacy and ensure transparency. Explainable AI (XAI) makes AI decisions interpretable by healthcare professionals, promoting ethical implementation and acceptance of AI technologies in safety management.

These applications demonstrate how AI and smart technologies address essential safety challenges in the health sector, leading to improved operational efficiency, enhanced safety outcomes, and sustainable health management. Table 7 shows AI and smart technology research methods for safety management factors in the health sector. By integrating AI methodologies into safety management, the health sector can achieve significant advancements in safety protocols, emergency response effectiveness, and overall health outcomes.

**Table 7.** AI and smart technology research methods for safety management factors in the health sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Occupational Risk Management and Prevention** | - Conducted risk analysis, including identification, analysis, and evaluation of occupational hazards.<br>- Developed AI-based predictive analytics and machine learning algorithms to assess healthcare workers' exposure to risks.<br>- Implemented safety management systems utilizing smartphone GPS technologies. | [66,67] |
| **Smart Health Monitoring and Prevention** | - Developed wearable devices with AI and IoT sensors for real-time physiological data collection (e.g., heart rate, blood pressure).<br>- Integrated EEG and ECG sensors in smart masks with mobile apps for displaying health metrics.<br>- Utilized digital twin models for real-time safety scenario simulations and assessments. | [65] |
| **Mental Health Management and Prevention** | - Implemented AI chatbots and applications using natural language processing for mental health support.<br>- Applied machine learning models to identify signs of mental health issues from user interactions.<br>- Utilized predictive analytics and wearable sensors to monitor and prevent mental health crises. | [68] |
| **Technological Integration and Ethical Implementation** | - Developed AI governance frameworks to ensure ethical use of AI in smart cities.<br>- Employed secure data management practices to protect patient privacy and ensure transparency.<br>- Utilized explainable AI (XAI) to make AI decisions interpretable by healthcare professionals.<br>- Integrated cloud and edge computing for efficient data processing and management. | [66] |

#### 3.2.7. Integration of AI and Smart Technologies in Safety Management for Smart Home and Living

In the smart home and living sector, AI and smart technologies significantly enhance safety management by addressing critical factors such as accident prevention, legal compliance, human life protection, property protection, operational efficiency, fire and CO poisoning prevention, energy management, and health management. AI-driven solutions include ontology-based approaches using Web Ontology Language (OWL) and Semantic Web Rule Language (SWRL) to build comprehensive risk recognition systems. Intelligent gas meters and automated fire suppression systems manage gas-related risks effectively, while Non-Intrusive Appliance Load Monitoring (NIALM) utilizes machine learning algorithms to monitor and control appliance usage, optimizing energy consumption and preventing electrical faults. Smart health monitoring systems integrate IoT sensors and predictive models to continuously assess residents' health and environmental conditions.

AI-powered security systems employ computer vision and anomaly detection to protect property by identifying unauthorized access or unusual activities. Additionally, AI governance frameworks ensure the ethical implementation of these technologies, safeguarding data privacy and promoting transparency. Real-time monitoring and alert systems leverage wireless modularization and networking technologies to provide immediate responses to potential hazards, enhancing overall safety and operational efficiency.

Furthermore, digital twin models simulate safety scenarios in real time, offering immersive fire and CO poisoning prevention through advanced sensor integration and predictive analytics. Table 8 provides information on AI and smart technology research methods for safety management factors in the smart home and living sector. These applications demonstrate how AI and smart technologies effectively address safety challenges in smart homes, leading to improved safety, security, efficiency, and health outcomes for residents.

**Table 8.** AI and smart technology research methods for safety management factors in the smart home and living sector.

| Safety Management Factor | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Accident Prevention** | - Developed ontology-based systems using OWL and SWRL for risk recognition.<br>- Implemented intelligent gas meters and automated fire suppression systems.<br>- Utilized NIALM with machine learning algorithms for appliance monitoring and control. | [69,70] |
| **Legal Requirements** | - Designed web-based safety management frameworks to ensure compliance with safety regulations.<br>- Integrated AI governance frameworks to protect data privacy and ensure ethical AI implementation. | [69] |
| **Human Life Protection** | - Developed AI-powered emergency response systems and health monitoring devices.<br>- Integrated wearable sensors for real-time health data collection and anomaly detection.<br>- Utilized predictive models for timely health interventions. | [71] |
| **Property Protection** | - Employed AI security systems with computer vision and anomaly detection to monitor for unauthorized access.<br>- Implemented smart surveillance systems to detect unusual activities and prevent theft or damage. | [70] |
| **Improvement of Operational Efficiency** | - Utilized AI-driven resource optimization systems for efficient energy management.<br>- Implemented smart meters and automated power control systems to reduce energy consumption and prevent system failures.<br>- Integrated sustainable development (SD) principles with IoT and KM for robust management. | [70] |
| **Fire and CO Poisoning Prevention** | - Designed smart home IAQ monitoring systems with CO sensors and predictive models.<br>- Utilized digital twin models for immersive fire and CO poisoning prevention.<br>- Conducted scenario-based performance assessments and system tests for reliability. | [70,71] |
| **Energy Management** | - Developed AI-powered predictive models to analyze and optimize energy consumption.<br>- Implemented energy-efficient solutions through smart meters and automated control systems.<br>- Employed digital twin simulations to enhance energy efficiency strategies. | [70] |
| **Health Management** | - Integrated AI and IoT sensors in wearable devices for continuous health monitoring.<br>- Developed mobile applications to display health metrics and provide personalized recommendations.<br>- Utilized predictive analytics for early detection of health issues. | [71] |

#### 3.2.8. Integration of AI and Smart Technologies in Safety Management for Other Sectors

In the "other sectors", AI and smart technologies significantly enhance safety management by addressing critical factors such as accident prevention and risk management, workplace and facility safety management, quality assurance and reliability management, and system-based safety enhancement. AI-driven solutions leverage sensor networks, location-based services (LBSs), and natural language processing to proactively identify and mitigate potential hazards. For instance, the u-Food System utilizes sensor tags and LBS to monitor and ensure the quality of food distribution, while predictive modeling combines public and internal recall data to forecast and prevent food-related risks.

Workplace safety and facility safety are improved through AI-powered monitoring systems that employ IoT sensors and computer vision to detect equipment malfunctions and unsafe behaviors in real time. Quality assurance is enhanced by anomaly detection algorithms that identify defects early in the production process, ensuring compliance with safety standards and increasing product reliability. Additionally, system-based safety enhancements are achieved through AI-driven automation and smart control systems, which optimize operations and reduce human exposure to hazardous tasks. Table 9 organizes and presents AI and smart technology research methods for safety management factors in the other sectors. The ISO/IEC/IEEE 15288:2023 standard, titled "Systems and Software Engineering—System Life Cycle Processes", is implemented to identify stakeholders and establish Measures of Effectiveness (MOEs), ensuring alignment with operational goals and safety protocols. This standard also guides the implementation of AI-based system requirements decomposition and stakeholder satisfaction assessments, contributing to a structured approach to safety management and technological integration. These integrations of AI and smart technologies demonstrate their effectiveness in addressing diverse safety challenges, leading to improved safety outcomes and enhanced operational efficiency across various industries [77].

**Table 9.** AI and smart technology research methods for safety management factors in the other sectors.

| Safety Management Factors | AI and Smart Technology Research Methods | Research Number |
|---|---|---|
| **Accident Prevention and Risk Management** | - Developed u-Food System with sensor tags, sensor networks, and Location-Based Services (LBSs) for smart quality distribution.<br>- Utilized natural language processing and predictive modeling to combine public and internal recall data for customized risk prediction.<br>- Implemented systematic processes for selecting and deploying risk-prevention technologies. | [72–76] |
| **Workplace and Facility Safety Management** | - Employed AI-powered monitoring systems with IoT sensors and computer vision for real-time surveillance.<br>- Designed smart home IAQ monitoring systems with CO sensors and predictive models.<br>- Utilized Arduino-based liquid level detection systems for continuous monitoring and hazard prevention. | [72,73,76] |
| **Quality Assurance and Reliability Management** | - Applied anomaly detection algorithms to identify defects in products and processes early.<br>- Conducted food hygiene monitoring using salinity measurement, microbial analysis, and statistical analysis.<br>- Implemented ISO/IEC 15288 standards to identify stakeholders and establish Measures of Effectiveness (MOEs). | [72,74,75] |
| **System-based Safety Enhancement** | - Developed AI-driven automation and smart control systems to optimize operations.<br>- Utilized digital twin models for real-time safety scenario simulations.<br>- Implemented AI-based system requirements decomposition and stakeholder satisfaction assessments using ISO/IEC 15288. | [73,74,76] |

## 4. Discussion

The rapid advancement of Artificial Intelligence (AI) and smart technologies within the Safety 4.0 paradigm has fundamentally transformed safety management practices across various sectors. This study systematically identified and analyzed how AI and smart technologies are currently utilized to enhance safety management factors, examining specific applications, technologies used, algorithms implemented, and the contexts in which they are applied. The analysis revealed patterns, trends, insights, and future directions that inform developments and practical implementations in safety management.

## *4.1. AI Applications in Safety Management Across Industries*

### 4.1.1. Construction Sector

In the construction sector, AI and smart technologies address safety factors such as real-time hazard detection, predictive analytics, and enhanced training. These innovations help mitigate workplace accidents, improving worker safety and reducing the economic burden of injuries. For example, AI-powered safety management systems utilize IoT sensors and machine learning algorithms to monitor safety data in real time, predicting potential hazards and enabling proactive interventions. Furthermore, computer vision technologies detect unsafe behaviors through automated image recognition, while Virtual Reality (VR) and Augmented Reality (AR) provide immersive training environments, improving hazard recognition and response. These systems enhance both operational efficiency and worker protection, highlighting AI's societal and practical impact on construction safety [78,79].

### 4.1.2. Industrial Safety Sector

In the industrial safety sector, AI contributes to data-driven decision-making and real-time monitoring, enhancing safety performance and operational productivity. Machine learning models analyze vast amounts of safety incident data to identify risk factors and improve Safety Performance Indicators (SPIs). AI-powered monitoring systems with IoT sensors facilitate immediate hazard detection and mitigation, reducing human error and operational costs. These technologies also support proactive safety cultures, where resources are allocated efficiently using multi-criteria decision analysis (MCDA) frameworks to minimize risks in high-stress industrial environments [79,80].

### 4.1.3. Disaster and Public Safety Sector

AI technologies significantly enhance urbanization and disaster management by improving public safety through advanced analytics and integration of Big Data. Predictive models forecast disasters like floods and fires, while digital twin technologies simulate disaster scenarios, improving preparedness and response strategies. These systems minimize casualties and property damage, demonstrating AI's societal relevance in addressing large-scale safety challenges. AI-driven platforms that incorporate real-time data from intelligent CCTV and social networks further optimize emergency management [78,79].

### 4.1.4. Transport and Logistics Sector

AI addresses safety factors in the transport and logistics sector, including traffic accident prevention, railway safety, maritime safety, and public transport safety. Predictive models and machine learning algorithms analyze real-time traffic data to prevent accidents, enhance safety protocols, and reduce operational disruptions. For example, AI-powered IoT systems detect equipment anomalies in railways, optimizing maintenance schedules. Similarly, AI-driven navigation systems in maritime contexts prevent collisions, while enhanced surveillance in public transport improves security and operational efficiency [81].

### 4.1.5. Energy and Power Sector

In the energy and power sector, AI improves safety management factors such as gas safety and risk management, power grid and energy optimization, and real-time monitoring. Intelligent gas meters and automated fire suppression systems effectively manage gas-related risks, while smart meters prioritize power supply to prevent electrical faults. AI governance frameworks ensure responsible and efficient resource use, further supported by Big Data Analysis (BD Analysis) to identify fire hotspots and optimize firefighting strategies. These applications contribute to societal resilience and industrial sustainability [78,79].

#### 4.1.6. Health Sector

AI enhances safety in the health sector by addressing occupational risks, smart health monitoring, mental health management, and ethical implementation. Predictive analytics help prevent workplace accidents by analyzing healthcare workers' exposure to risks. Wearable devices integrated with IoT sensors monitor physiological data in real time, detecting anomalies and offering personalized health recommendations. These innovations support not only worker well-being but also operational safety, aligning with societal goals for health and safety [81].

#### 4.1.7. Smart Home and Living Sector

In the smart home and living sector, AI technologies address critical safety and efficiency factors such as accident prevention, fire and CO poisoning prevention, and energy management. Ontology-based approaches and Natural Language Processing (NLP) systems enhance hazard recognition, while AI-driven monitoring systems detect risks like gas leaks and electrical faults. These technologies optimize operational efficiency and protect human lives, underscoring their societal significance in improving living conditions [78].

#### 4.1.8. Other Sectors

Across other sectors, AI enhances safety management through accident prevention, workplace safety optimization, and quality assurance. Predictive analytics and sensor networks proactively mitigate potential hazards, while anomaly detection algorithms ensure reliability in production processes. These advancements demonstrate AI's transformative role in addressing safety and operational challenges, contributing to societal well-being and industrial sustainability [79,80].

### *4.2. Patterns, Trends, and Insights*

#### 4.2.1. Shift from Reactive to Proactive Safety Management

A significant trend across sectors is the shift from reactive to proactive safety management enabled by AI. Predictive analytics and real-time monitoring allow organizations to anticipate and mitigate risks before incidents occur, enhancing overall safety outcomes.

#### 4.2.2. Integration of AI with IoT and Big Data

The convergence of AI with IoT devices and Big Data analytics facilitates real-time data collection, analysis, and decision-making. This integration enhances the speed and accuracy of safety interventions, leading to more efficient and effective safety management practices.

#### 4.2.3. Ethical Considerations and Data Privacy

As AI becomes more integrated into safety management, ethical considerations and data privacy emerge as critical concerns. Ensuring transparent, explainable AI (XAI) models and securing personal and sensitive data are essential for maintaining trust and compliance with regulations.

### *4.3. Future Directions of Safety 4.0 and AI Development*

#### 4.3.1. Expansion into Underexplored Safety Management Factors

Future research should explore AI applications in safety management factors that are currently underrepresented, such as mental health management in high-stress industries and ethical AI implementation.

#### 4.3.2. Advancement of Explainable AI (XAI)

Developing explainable AI models is crucial for ensuring that AI decisions are interpretable by stakeholders, fostering trust and facilitating the adoption of AI in safety-critical applications.

#### 4.3.3. Integration of AI with Emerging Technologies

Combining AI with emerging technologies like Edge Computing, 5G connectivity, and Blockchain can further enhance safety management by improving data processing speeds, ensuring secure data transmission, and maintaining tamper-proof records.

#### 4.3.4. Addressing AI-Related Risks and Ethical Issues

AI development must consider potential risks such as algorithmic bias and over-reliance on automated systems. Establishing ethical guidelines and regulatory frameworks will help mitigate these risks and promote responsible AI deployment.

#### 4.3.5. Enhancing Human–AI Collaboration

Promoting effective collaboration between humans and AI systems can leverage the strengths of both, enhancing overall system performance and safety outcomes through user-friendly interfaces and intuitive interaction methods.

#### 4.3.6. Global Standardization and Best Practices

Developing international standards and best practices for AI integration in safety management will promote consistency and reliability across industries, ensuring that safety measures are universally effective and trustworthy.

#### 4.3.7. Fostering Interdisciplinary Research and Education

Encouraging interdisciplinary research that brings together experts in AI, safety management, ethics, and human factors will drive comprehensive solutions. Educational programs that equip professionals with both technical and domain-specific knowledge are essential for the effective implementation of AI in safety management.

### *4.4. Limitations*

This study focused on the literature with "Safety management" and "Smart", "AI", or "Artificial Intelligence" in the titles, potentially overlooking relevant studies without these keywords. Consequently, the analysis may not fully represent the breadth of AI applications in safety management. Future research should employ broader search strategies, including keywords like "Machine Learning", "Deep Learning", and "Data-Driven", and consider full-text searches to capture a more comprehensive range of studies.

## 5. Conclusions

This study systematically identified and analyzed how Artificial Intelligence (AI) and smart technologies are currently utilized to enhance safety management factors across various sectors within the Safety 4.0 paradigm. By examining specific applications, technologies used, algorithms implemented, and the contexts in which they are applied, a comprehensive understanding of AI's transformative role in safety management practices was achieved.

AI facilitates predictive analytics, real-time monitoring, and automated decision-making, enabling proactive and adaptive safety strategies. These strategies reduce risks, optimize resources, and improve operational efficiency, ultimately fostering safer and more sustainable industrial ecosystems. Successful implementation requires a multidisciplinary approach that integrates organizational commitment, regulatory compliance, and ethical oversight. Human factors—such as workforce training, technology acceptance, and user-centered design—are equally critical. Ensuring transparency and accountability through explainable AI (XAI) models builds stakeholder trust and supports widespread adoption.

Future research should address underrepresented safety factors, including mental health in high-stress industries while exploring emerging technologies like edge computing, Blockchain, and 5G within safety frameworks. Developing standardized protocols and industry-specific guidelines will bridge the gap between theoretical research and practical application, allowing industries to fully leverage AI's potential for reducing accidents and achieving long-term sustainability.

Embracing AI and smart technologies under the Safety 4.0 paradigm will not only revolutionize safety management but also advance societal well-being and sustainable industrial growth. This paradigm shift paves the way for a safer, more resilient future for all stakeholders.

**Author Contributions:** Data curation, J.P. and D.K.; funding acquisition, J.P.; investigation, J.P. and D.K.; methodology, J.P.; conceptualization, J.P. and D.K.; project administration, J.P.; visualization, J.P.; formal analysis, J.P. and D.K.; writing—original draft preparation, J.P. and D.K.; writing—review and editing, J.P. and D.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This paper was supported by a grant from Wonkwang University, Republic of Korea, in 2024.

**Informed Consent Statement:** All participants in this study will provide informed consent.

**Data Availability Statement:** The authors will make the data available upon reasonable request.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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