Open Journal of Safety Science and Technology, 2025, 15(4), 311-332
https://www.scirp.org/journal/ojsst
ISSN Online: 2162-6006
ISSN Print: 2162-5999

Assessing the Effectiveness of IoT-Based Safety Monitoring Systems in Mitigating Workplace Hazards: A Systems Engineering Approach

John Atabong Zifac

Liberty University, Lynchburg, USA
Email: john_atabong@yahoo.com

How to cite this paper: Zifac, J.A. (2025) Assessing the Effectiveness of IoT-Based Safety Monitoring Systems in Mitigating Workplace Hazards: A Systems Engineering Approach. *Open Journal of Safety Science and Technology*, **15**, 311-332.
https://doi.org/10.4236/ojsst.2025.154017

Received: April 29, 2025
Accepted: October 27, 2025
Published: October 30, 2025

Abstract

This comprehensive study examines how IoT-based safety monitoring systems improve workplace safety in the general industry. The study utilizes secondary qualitative approach to collect data and analyze it by the help of narrative analysis. Systems engineering techniques are used to develop, optimize, and manage these systems, emphasizing stakeholder demands, system requirements definition, system architecture design, and risk assessment and mitigation. The article identifies some drawbacks of these systems, including technological issues and privacy concerns. Thus, the research recommends integrating IoT-based tools into a safety management approach rather than using them alone. The study finds that IoT-based safety monitoring systems, driven by research, system enhancement, and user acceptability, can change safety management across sectors.

Keywords

IoT (Internet of Things), Workplace Safety, Safety Monitoring Systems, Systems Engineering, Industrial Hazards, Physical Hazards

1. Introduction

Workers in factories and other industrial settings are exposed to more hazards when working conditions change. Workplace protection is no surprise in today's world, where technology is everywhere. Workplace safety prevents accidents and illness in factories and offices. These general industries are diverse; thus, their threats are many. Some examples are physical, chemical, ergonomic, and biological risks [1].

Understanding these dangers is the first step to mitigating them. Physical hazards include everything that can hurt someone. Machinery, noise, temperature extremes, and radiation are examples. Chemical dangers occur when personnel expose themselves to or directly in contact with hazardous substances. Repetitive motions, poor workspace layout, and poor body alignment are ergonomic dangers. Biohazardous workplaces expose workers to bacteria, viruses, fungi, and other microorganisms [2].

In addition, recent technology, specifically the IoT, offers hope for a safer future in these contexts. Sensors, devices, and software connected via the IoT monitor, analyze, and respond to possible risks in real time. These technologies collect and analyze data to identify patterns and improve workplace safety. This allows the devices to protect workers immediately and prevent workplace risks over time.

Business IoT growth is unstoppable. Over 50 billion gadgets connected by the IoT have transformed the industry. Smart cameras and biometric-monitoring wearables have changed workplace safety thanks to IoT [3]. As shown in **Figure 1**, OSHA identified the top 10 most frequently cited violations in 2021.

Figure 1. OSHA's 2021 top 10 most frequently cited violations [4].

Systems engineering is a multidisciplinary profession that develops and maintains complex systems. This field seeks efficiency and cost reduction. This strategy considers all stakeholders' commercial and technological needs to provide a high-quality design that meets users' needs. Systems engineering-based IoT-based safety monitoring systems can improve efficiency, dependability, and user satisfaction [5]. The common categories of workplace hazards are illustrated in **Figure 2.**

Given the complexity of workplaces and the wide range of possible hazards, a one-size-fits-all safety policy is insufficient. Furthermore, Systems engineering, which considers all aspects of the workplace, may provide a more complete solution. This method lets a person assess each hazard's dangers and take appropriate preventative measures.

Maintaining a competitive edge in a constantly evolving technological landscape requires proactively keeping pace with the latest advancements. Companies must implement IoT-based safety monitoring systems to respond to emerging situations; technology alone is not the answer. Researchers must use systems engineering to develop and deploy these systems successfully. Industry and workers may depend on this.

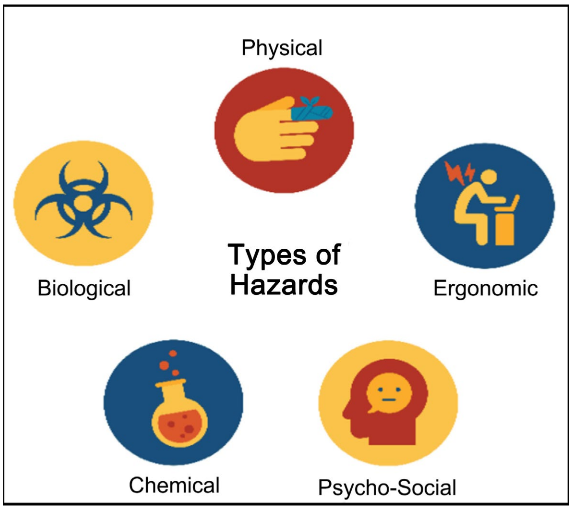

Figure 2. Common categories of workplace hazards [6].

2. Workplace Hazards in General Industries

2.1. Common Types of Workplace Hazards

Each industry has unique risks, and industrial workplaces are full of hazards. Management must first understand the risks to protect workers' health and safety. Workplace dangers range from physical to ergonomic [7]. The research also shows that these threats affect employee health, safety, corporate productivity, and efficiency.

Chemical, physical, ergonomic, and biological hazards are identified in research [8]. Physical threats include dangerous machinery, extreme noise, high temperatures, and radiation. Chemical risks involve long-term exposure to potentially harmful substances that can harm health. Ergonomic risks, including repetitive actions, improper workspace settings, and poor body alignment, can cause debilitating musculoskeletal issues. Ergonomic hazards are less noticeable than other threats. Finally, exposure to harmful biological substances in healthcare institutions and laboratories, including bacteria, viruses, and fungi, causes physical dangers. **Figure 3** shows fatal occupational injuries by major event or exposure between 2017 and 2021.

2.2. Impact of Workplace Hazards on Employee Safety and Productivity

Workers are especially likely to notice physical hazards like machinery accidents in industrial settings. According to the US Bureau of Labour Statistics, equipment contributed to 15% of fatal occupational injuries in 2020 [10]. Extreme noise, a physical hazard, can cause hearing loss and other auditory issues, affecting more than 22 million US workers annually.

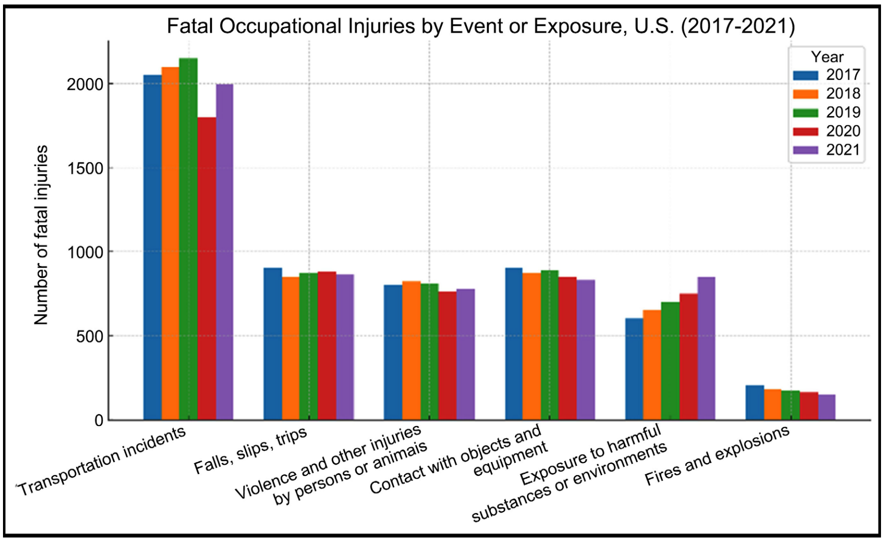

Figure 3. Fatal occupational injuries by event or exposure [9].

Chemical hazards often have more subtle and long-term effects on workers. Long-term chemical exposure can cause chronic respiratory, skin, and cancer [11]. According to [12], construction and industry employees are at risk of chemical exposure despite using protective gear.

Ergonomic hazards, albeit less evident, can also harm employees. According to published data, work-related musculoskeletal problems cause 33% of worker illnesses and injuries [13]. These injuries affect the worker and the industry in terms of medical costs, productivity, and absenteeism.

These threats affect productivity and operational efficiency. A 2019 National Safety Council research found that work-related deaths and injuries cost $171 billion [14]. This includes salary losses, medical bills, and administrative costs. Workplace dangers impair employees' physical and mental well-being, and they influence the industries financially. As shown in **Figure 4**, musculoskeletal disorders (MSKD) vary across conditions.

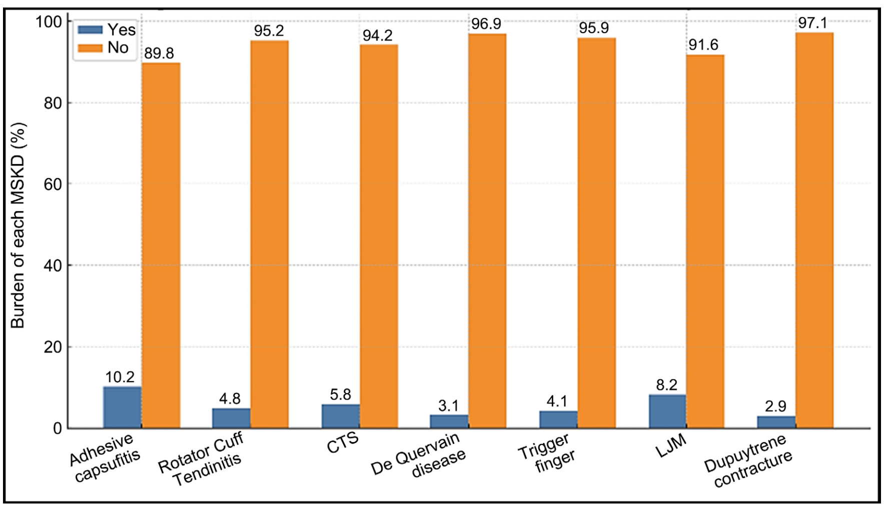

Figure 4. Burden of musculoskeletal disorders (MSKD) by condition [15].

In summary, workplace hazards research depicts a complex and dangerous environment with severe consequences for people and their industries. Understanding risks and their effects is the first step to safer, healthier, and more productive workplaces.

3. IoT-Based Safety Monitoring Systems

The internet connectivity of many devices has disrupted several industries, including workplace safety. Safety monitoring systems use IoT sensors, devices, and software. These real-time detection and mitigation solutions revolutionize workplace safety [16].

These systems have several vital pieces. IoT sensors can measure temperature, humidity, noise, and vibration. These sensors can be placed on machines, workstations, or even staff devices to collect data about the workplace. Data is transmitted to a cloud-based data processing system via a network connection, and the data is analyzed and used. These insights can trigger automatic notifications or actions to decrease hazards. An alert, machine shutdown, or supervisor notification can occur. Data keep for long-term trend study and workplace danger avoidance.

IoT-based safety monitoring systems have many benefits. First, they provide real-time monitoring and fast response, which reduces accident risk. Instead of manual inspections and reports, these systems can continuously monitor and inform supervisors or workers of potential threats [17]. These systems also identify patterns and trends over time, which allows for preventative measures and safety process improvements.

IoT solutions can also lessen ergonomic and chemical concerns. Wearable IoT devices can monitor employees' postures and motions, identify ergonomic risks, and provide solutions. Internet-connected sensors can monitor air quality and detect toxic chemical contaminants, protecting workers from exposure.

IoT-based safety monitoring systems provide benefits but also drawbacks. These systems require expensive hardware, software, and training to deploy. Implementation requires these costs. Data privacy and security concerns are major due to the sensitive nature of the data acquired and the likelihood of cyberattacks [18]. Signal interference, sensor accuracy, and system stability are concerns for IoT system dependability.

According to studies, IoT-based safety monitoring systems improve workplace safety [19]. They provide real-time monitoring, instant response, and long-term danger prevention techniques. However, implementing them requires careful consideration of several issues, including system stability, cost, and data privacy.

The Effectiveness of IoT-Based Safety Monitoring Systems in Reducing Hazards

Recent studies show that IoT-based safety monitoring solutions reduce workplace dangers. Rio Tinto, the world's most significant metals and mining company, has used IoT technologies for years [20]. Rio Tinto understood hundreds of its workers were in dangerous conditions and needed proactive safety measures. This led to the Mine of the Future program, an IoT-based safety system. This system uses thousands of IoT sensors to monitor real-time mining activities. These include equipment, environment, and worker health. To identify risks and take precautions, use data. IoT has improved workplace safety by reducing equipment damage, operational downtime, and workplace accidents.

The building is another case study. Skanska's workplace safety strategy includes smart helmets with IoT sensors [21]. During their shifts, workers must wear these helmets, which monitor temperature, humidity, noise, and impact. An alert will ring if any parameter exceeds the safety level, and the notification will be sent to appropriate parties. Skanska claims smart helmets have reduced workplace accidents and improved workers' safety awareness and compliance. The applications of IoT in industrial workplaces are highlighted in **Figure 5**.

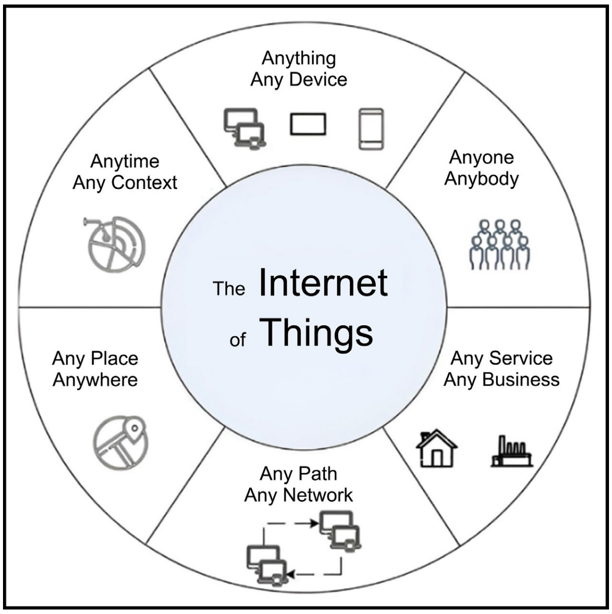

Figure 5. Uses of IoT in general industries [22].

Bosch, a multinational engineering and technology company that manufactures automotive and industrial technology, has installed an IoT-based safety system at its production facilities [23]. The Bosch Production System monitors machine function and ergonomics using sensors connected to the IoT. The system can immediately shut down machines to reduce ergonomic hazards and give workers feedback on their postures and actions. Bosch has reduced workplace injuries since implementing this technique. This shows that IoT can eliminate many workplace risks.

These case studies demonstrate how IoT-based safety monitoring solutions may alter various enterprises. These technologies reduce workplace injuries in mining, building, and manufacturing plants while promoting safety. However, careful design, proper implementation, and ongoing monitoring are needed to achieve these benefits, emphasizing the need for a system engineering approach when deploying IoT-based safety systems.

4. Systems Engineering Modeling Accuracy Methodologies

4.1. Systems Engineering Overview

Systems engineering is an interdisciplinary field that designs, integrates, and manages complex systems throughout their life cycles [24]. It includes determining client demands and desired functionality early in the development cycle, system design, integration, validation, operations, maintenance, and disposal. Systems engineering relies on seeing everything as part of a more extensive system to coordinate multiple components for the desired result efficiently. The IoT-based framework for workplace safety is presented in **Figure 6**.

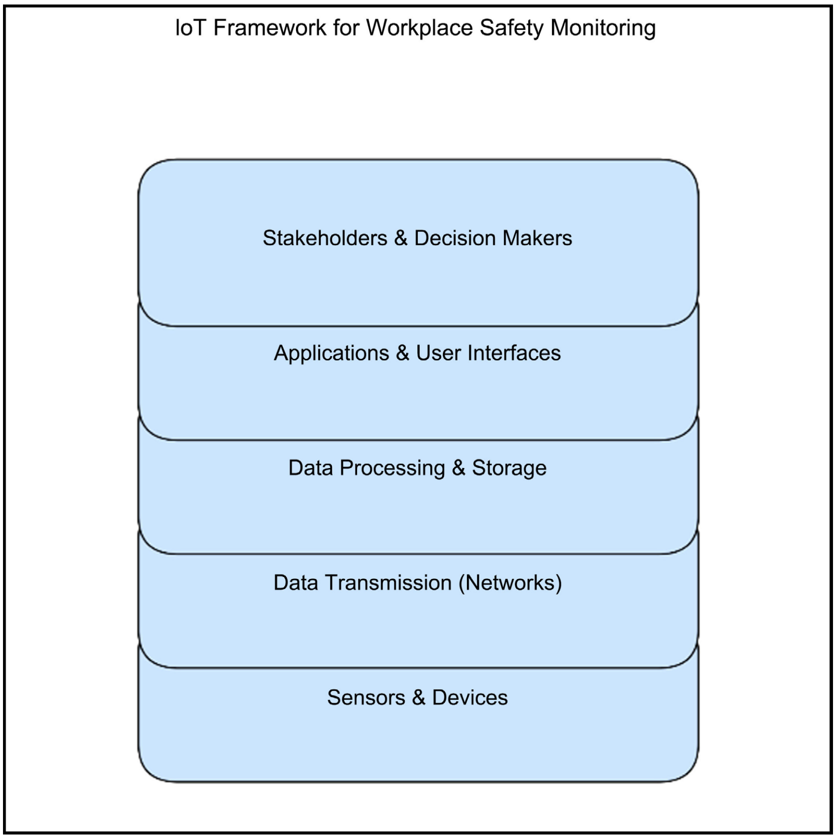

Figure 6. IoT framework for workplace safety monitoring [25].

"Systems thinking," defined as "understanding a system by examining the linkages and interactions between the components that comprise the entirety of that defined system," is the cornerstone of systems engineering. It recognizes that evaluating a system is the only way to understand its behavior. Whole-systems approach. In complex systems like an IoT-based safety monitoring system, sensors, network connections, data processors, and human operators must work together without interruption.

4.2. Systems Engineering Helps Design and Implement Safety Monitoring Systems

Systems engineering helps create and deploy safety monitoring systems. Systems engineering ensures that all design aspects, such as hardware, software, users, and the environment, are considered and coordinated [26] [27].

During design, systems engineering helps define system requirements based on user needs and the operational environment. This comprises selecting sensors, installing them, networking them, collecting data, and processing and using them. It also involves user interface design and system interaction. This holistic approach ensures the technology will work well in its intended setting and meet user needs.

Systems engineering ensures that all system components function correctly during implementation. This includes testing and certifying each member and the system, debugging and fixing any issues, and improving the system design.

Systems engineering helps monitor system performance, identify deviations, and take remedial action during operation and maintenance. It helps manage system upgrades and tweaks to ensure the system meets user needs and adjusts to operational changes.

Systems engineering provides a reliable framework for creating and implementing safety monitoring systems. Systems engineering considers all system parts and interactions to ensure efficiency, dependability, and adaptability. Safety and productivity will improve.

4.3. System Needs Analysis

System requirements analysis, an integral aspect of systems engineering, sets the stage for system design and execution [27]. This section identifies stakeholder needs for IoT-based safety monitoring solutions.

In this case, employees, managers, safety officers, regulatory officials, and customers are stakeholders. Each stakeholder has its quality control system expectations. Employees need a simple, inconspicuous system. The system must efficiently detect potential threats and alert staff. Managers and safety professionals need a system that provides actionable information for danger prevention, aids safety compliance, and integrates effortlessly with existing processes [28].

Interviews, surveys, focus groups, and general observation can help determine these needs and expectations. As the system design evolves, stakeholders should provide regular feedback. This ensures that the finished system meets users' needs, which boosts acceptance and efficacy.

4.4. Functional and Non-Functional Safety Monitoring System Requirements

The stakeholders identify and specify the system requirements. This procedure includes functional and non-functional safety monitoring system criteria.

Functional requirements define the system's capabilities. An IoT-based safety monitoring system can identify risks, alert users when hazards are found, collect and transfer data, analyze data to determine patterns and trends, and provide reports [29]. Describing each function's purpose, operation, and conditions is crucial. For each part, use cases must portray the user-system communication.

Non-functional requirements describe system operation. The team considers functionality, safety, dependability, usability, and compatibility. The system may need to perform in real-time, resist hacking, work dependably under extreme climatic conditions, be easily used, and communicate with other systems [30].

Functional and non-functional requirements should be SMART, *i.e.* specified, measurable, achievable, relevant, and time-bound, to provide transparency and objectivity in system design, implementation, and evaluation. All system stakeholders should document and agree on them. This ensures everyone understands the system's goals.

Finally, systems engineering requires the examination of system requirements. This research guarantees that the IoT-based safety monitoring system is built and executed to match workplace needs, optimizing its safety and productivity benefits. Identifying stakeholders' needs and expectations and specifying the system's functional and non-functional requirements achieves this.

5. System Architecture

5.1. Creating the Safety Monitoring System's Core Architecture

After determining and documenting system requirements, systems engineers design system architecture. This includes identifying the safety monitoring system's components, relationships, and how they interact to perform the required functions [31].

When designing the system's architecture, the team should consider the system topology, which refers to the actual arrangement of its components. This includes choosing where to put the IoT devices and sensors, how to connect them, where to store and process data, and how users will interact with the system. The team should base this structure on the operating environment, and the user needs to ensure the system can efficiently identify and respond to threats while being accessible and user-friendly.

Data flow, or system data mobility, is also essential. The team must decide what data the sensors will collect and how to convey, process, examine, and display it to users [32]. This flow must ensure data accuracy, currency, and actionability to make risk-prevention decisions.

The development team must consider modularity, scalability, and adaptability throughout the product development. Building a system with separate, interchangeable parts is called "modularity" and simplifies maintenance and upgrades [33]. Scalability involves designing a system to handle increasing workloads. A system that can adapt can handle changes in the operational environment, user needs, and regulatory requirements [34].

5.2. Integration of IoT Sensors and Data Processors

System architecture must emphasize integrating the safety monitoring system's numerous parts. IoT devices, sensors, and data processing components must work efficiently to complete tasks.

IoT devices and sensors act as the vigilant "eyes and ears" of the system, diligently monitoring for potential threats and collecting valuable data regarding the operational environment. The monitoring will depend on the threats to address; these devices may incorporate temperature, humidity, noise, vibration, motion, and many more sensors. These gadgets must be accurate, reliable, and commercially viable [35].

The system's "brain," the data processing components, decides what to do with sensor data and interprets it. This process involves cleaning and analyzing raw data, detecting trends and anomalies, and sending warnings or reports. Depending on the data's complexity and analysis, this technique may involve data analytics, machine learning, or artificial intelligence [36].

Integrating these components requires testing their communication and efficiency. This requires suitable communication protocols, data formats, and interfaces. The integrated system must be validated and tested to ensure proper operation.

Finally, system engineering begins with system architecture design. This procedure creates the safety monitoring system's broad framework and integrates its many components to ensure it can efficiently perform its functions and react to changes. This technique boosts the system's workplace safety effectiveness. As shown below (**Figure 7**), a layered IoT architecture is commonly applied for safety monitoring.

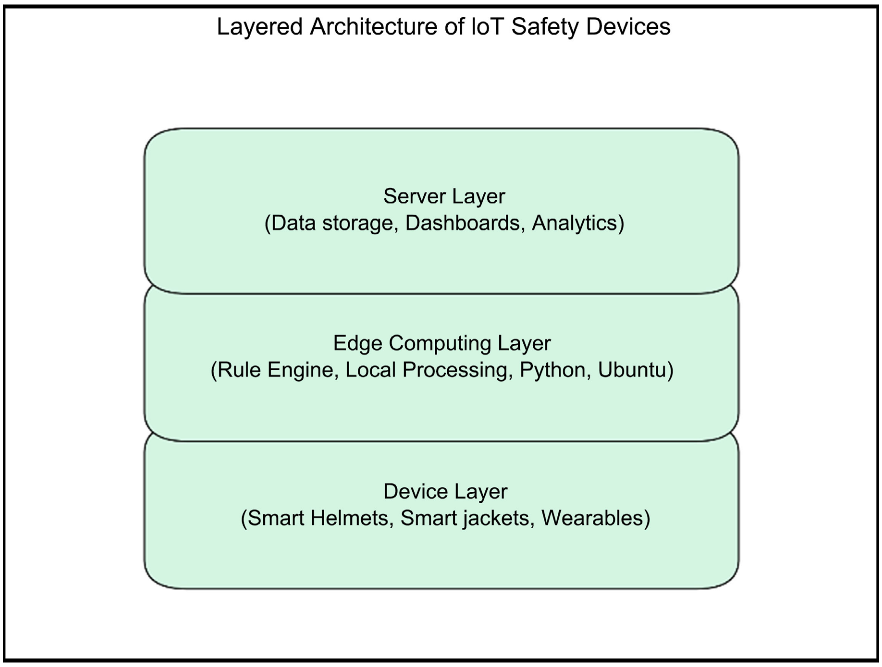

Figure 7. Layered IoT architecture for workplace safety systems [37].

6. Risk Assessment and Prevention

6.1. System Risk Assessment

Systems engineering and safety monitoring system strategy, development, and execution require risk assessment. It involves detecting system risks and quantifying their likelihood and impact. In addition, an IoT-based safety monitoring system may encounter threats from faulty hardware or software, network interruptions, data breaches, user errors, and environmental factors [38]. Furthermore, a sensor could fail, a software error could cause inaccurate data processing, a network outage could cause communication issues, a hacker could access sensitive data, a user could abuse the system, or a change in the environment could affect the system's function [39].

To detect these risks, one must understand the system, its operational environment, and the consequences of breakdowns or interruptions. This procedure may use fault tree analysis, FMEA, HAZOP, and risk matrix analysis. Importantly, this technique should be iterative, requiring ongoing reassessment as the system architecture changes and new information becomes available.

6.2. Privacy Challenges in IoT Safety Systems

Data security and privacy in IoT safety systems present complex issues that require careful consideration. The volume and variety of sensitive data created and shared across networked devices sometimes cause privacy difficulties in these systems. These issues arise from device interconnectivity, generating a large attack surface for malevolent actors. The variety of data formats and communication protocols in IoT systems makes privacy safeguards difficult. Understanding these issues is essential to solving them.

Current IoT safety system privacy solutions include encryption, access controls, and secure communication protocols. Current security tactics typically fail to handle the changing nature of security threats. Quantum computing may make encryption susceptible, threatening data security. Access controls regulating user permissions may struggle in IoT networks as devices join and leave. Centralized security procedures create single points of failure that could compromise the entire system if exploited.

Critical analysis of these methods shows flaws that should be addressed. Many static security measures fail in an ever-changing threat environment. IoT ecosystems are large and complex, requiring adaptive and anticipatory security. Existing methods lack the agility and foresight to address privacy issues of IoT safety systems, which are constantly changing.

Innovative and adaptable techniques are needed to overcome these constraints and improve privacy protection. This entails testing improved encryption techniques that can withstand quantum computing attacks. By spreading responsibility across the network, decentralized security models can reduce the effect of breaches. Another interesting approach is real-time threat identification and mitigation using AI. Machine learning algorithms allow IoT systems to adapt and respond to new threats in real-time, improving security.

The IoT community must advocate for standardized security mechanisms to build a cohesive and effective privacy approach. Industry stakeholders can collaborate to provide a framework for data security and privacy in networked systems. In conclusion, IoT safety systems must change from static and centralized privacy techniques to inventive, adaptable, and collaborative ones that can withstand changing security threats.

6.3. Risk Minimization in System Design and Operation

Risk reduction happens after hazard identification. These steps reduce the likelihood or severity of some dangers [40]. Redundancy, variety, fault tolerance, and robustness can minimize the risk during project design. Redundancy is having backups take over if a critical component fails. Diverse elements are needed to prevent common-mode failures. If it malfunctions, the team must build the system to operate at a reduced capacity. This is “fault tolerance.” Creating a plan to withstand operational environment changes is called robustness.

Monitoring, maintenance, training, and incident response may reduce risk during project operation. Monitoring involves regularly checking the system’s performance and health for signs of trouble. Regular system checkups and repairs prevent issues. To utilize the technology safely and effectively, users should be trained. Event response involves techniques and protocols for event management and recovery [41].

Systems engineering requires risk assessment and mitigation. This process identifies hazards and implements remedies to make the safety monitoring system reliable, secure, and resilient [42]. This procedure boosts the safety monitoring system’s workplace safety efficacy.

7. Integration of Smart Helmets and Smart Jackets for Comprehensive Safety Monitoring

Smart helmets and jackets in IoT-based safety monitoring systems ensure general industry worker safety. These wearable devices with multiple sensors monitor the wearer’s physiological and work environment. Organizations can create advanced hazard detection and early warning systems using smart helmets and jacket data [43]. If the smart jacket detects a sudden temperature rise or toxic gases, it can alert the smart helmet, which can then alert the worker. This integration allows real-time responses and proactive injury prevention.

Smart jackets and helmets with GPS enable real-time worker location tracking. Supervisors and safety personnel can quickly locate workers in emergencies and hazardous events, speeding up rescue efforts. Smart jackets also allow two-way communication between workers and control centers, enabling immediate assistance and coordinated response in critical situations [44]. Location tracking and emergency response capabilities improve worker safety and ensure timely service.

These devices also enable a complete occupational risk assessment. Organizations can learn about environmental conditions, physiological parameters, and hazards by correlating sensor data [45]. This holistic risk assessment allows organizations to proactively manage and mitigate risks, making data-driven decisions to create safer workplaces.

Integration may aid worker training and awareness programs. Smart helmets and jackets can identify behavior, movement, and risk exposure patterns [46]. Workers can receive personalized feedback and guidance from this data, supporting targeted training. These wearable devices can help organizations promote safety, worker awareness, and safer practices.

Smart helmets and jackets in IoT-based safety monitoring systems reduce worker hazards in the general industry comprehensively and proactively. Organizations can identify risks and respond quickly with enhanced sensory monitoring, real-time hazard detection, location tracking, and emergency response. The integration also promotes worker safety and targeted training. These technologies can make workplaces safer and protect employees.

7.1. Description of Intelligent Helmets and Their Key Features

Smart helmets improve worker safety across industries. They use advanced technologies to monitor, protect, and improve worker well-being. These helmets have sensors, communication, and data processing. Intelligent helmets have features like:

- ***Sensor Integration***

Smart helmets have real-time sensors [47] [55]. Examples include accelerometers, gyroscopes, temperature sensors, heart rate monitors, and gas detectors. Sensors continuously monitor the wearer's physiology and environment, revealing potential hazards (**Figure 8**).

Sensor Type	Purpose
Accelerometers	Measure acceleration and movement
Gyroscopes	Track orientation and rotation
Temperature Sensors	Monitor environmental temperature
Heart Rate Monitors	Track worker's physiology
Gas Detectors	Detect hazardous gases

Figure 8. Smart Sensors (Self-Created). Source: Author's own illustration.

- ***Communication Systems***

Smart helmets often have Bluetooth or Wi-Fi to connect to other devices or a central control center [48]. This allows direct data transmission and worker-supervisor communication, improving safety coordination.

- ***Augmented Reality***

Head-mounted displays in smart helmets aid employees. These displays deliver real-time environmental data, safety alerts, and directions to workers, improving situational awareness. Workers can make safe decisions by obtaining fast alerts on potential hazards. These immersive displays seamlessly integrate information into the worker's field of vision, eliminating distractions and helping them focus. This technology improves workplace safety, efficiency, productivity, and risk management by keeping workers connected and informed.

- ***Real-time physiological monitoring***

Smart helmets' real-time physiological monitoring is essential. The helmet monitors heart rate, body temperature, and brain activity. This monitoring helps early detect and treat fatigue, heat stress, and other health issues. Real-time physiological monitoring alerts workers and supervisors to health risks.

- ***Hazard detection and early warning***

Smart helmets detect and warn of hazards. These helmets can detect many workplace hazards using sensor data. The main features of the smart helmet are illustrated below (**Figure 9**):

The smart helmet can alert the wearer visually or audibly if toxic gases or temperatures rise unexpectedly [50]. This early warning system allows workers to move to a safe location or put on protective gear to prevent accidents and injuries. Risky industries benefit from hazard detection and early warning systems.

- ***Tracking and emergency response***

Smart helmets can track and respond to emergencies. Smart helmets with GPS allow real-time worker tracking. Supervisors or safety personnel can quickly locate affected workers in emergencies or hazardous events, speeding up rescue operations. Smart helmets may have distress signals or emergency call buttons to help workers get help quickly [51]. Location tracking and emergency response improve worker safety by providing reliable communication and support during critical moments. The features of the Smart helmet are also explained in **Figure 9**.

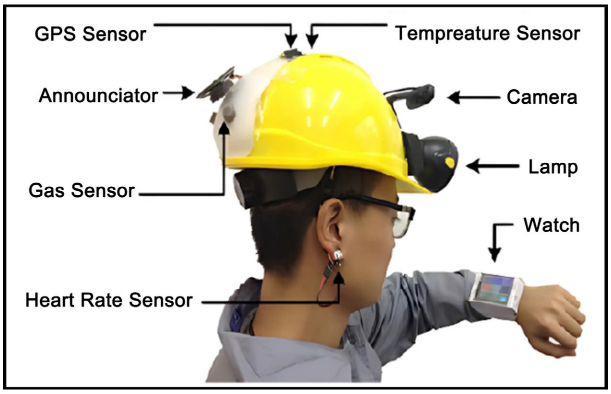

Figure 9. Key features of a smart helmet for workplace safety [49].

Smart helmets enhance worker safety in the general industry. These helmets protect workers in hazardous environments with sensor integration, real-time physiological monitoring, hazard detection and early warning systems, location tracking, and emergency response. Continuous vital sign monitoring and real-time hazard detection and response improve worker safety and allow proactive risk mitigation.

7.2. Smart Jacket Features

Smart jackets improve worker safety and comfort across industries. These jackets use cutting-edge technology to monitor environmental conditions, detect falls, and improve communication. Smart jackets have features like:

- ***Embedded environmental sensors.***

Smart jackets have environmental sensors [52]. These embedded sensors continuously monitor temperature, humidity, air quality, and toxic gases. Smart jackets help workers assess and mitigate risks by providing real-time data on these conditions. The Smart jacket can warn workers to evacuate or take precautions if toxic gas levels are high. Early warning and reduced exposure to hazardous environments improve worker safety.

- ***Fall Detection/Impact Monitoring***

Smart jackets detect falls and impact. Sensors track acceleration, orientation, and other parameters. The Smart jacket alerts if these readings change suddenly, indicating a fall or impact [53]. This prompt detection allows immediate response and assistance, especially in fall risk. Smart jackets reduce injuries, response time, and death by detecting falls and impacts.

7.3. Collaboration

Smart jackets aid workplace communication and collaboration [54]. Microphones, speakers, and wireless protocols allow workers to communicate with supervisors, coworkers, and control centers. This makes emergency communication fast and easy. Smart jackets with communication features allow workers to quickly share information, report hazards, and receive instructions, improving safety and productivity (**Figure 10**).

Sensor Type	Purpose
Accelerometers	Measure acceleration and movement
Gyroscopes	Track orientation and rotation
Temperature Sensors	Monitor environmental temperature
Heart Rate Monitors	Track worker's physiology
Gas Detectors	Detect hazardous gases

Figure 10. Functions of Smart Jacket (Self-Created). Source: Author's own illustration.

Smart jackets improve worker safety and communication across industries. Smart jackets mitigate risks and protect workers with environmental sensors, fall detection, impact monitoring, and communication and collaboration features.

Smart jackets improve safety, response time, and worker-supervisor collaboration by providing real-time ecological data, detecting falls and impacts, and promoting effective communication.

8. Discussion

8.1. Effectiveness of IoT-Based Safety Monitoring Systems in Reducing Workplace Hazards

Numerous research and comprehensive literature reviews suggest that IoT-based safety monitoring solutions can improve workplace safety. These technologies may reduce workplace dangers, improve worker safety, and boost manufacturing and construction efficiency [29].

IoT-based safety monitoring solutions use sensors to detect heat, machine vibration, and worker health in real time. These sensors track personnel, machines, and workplace risk zones [22]. IoT devices reduce accident risks with real-time data.

IoT-enabled wearables can detect hazards and give health data for scheduling optimization and worker comfort [56]. This is vital in manufacturing and construction, where physical stress causes occupational injuries.

Real-time data, risk management, and operational efficiency may improve workplace safety with IoT-based safety monitoring solutions. These advances promise safer and more productive workplaces across industries.

8.2. IoT-Based Systems in Professional Settings: Pros and Cons

IoT-based safety monitoring systems offer real-time monitoring, precise data, and prediction. However, industry constraints can affect these methods' efficiency. Real-time threat detection and staff health data can improve safety practices. However, less risky industries like technology may not benefit as much. Ergonomic changes and stress reduction programs may be better safety safeguards in these scenarios.

One downside of IoT is its reliance on technology. Technology issues can cause system failure, preventing danger detection. Thus, frequent maintenance and system updates are essential for reliability. Data security is needed to manage privacy issues related to collecting and storing workers' health data [57].

Finally, internet-of-things (IoT)-based safety monitoring solutions reduce occupational dangers, especially in high-risk industries. Tailoring these solutions to each sector's needs is essential. They should also augment, not replace, standard safety processes and be part of a comprehensive safety management strategy.

9. Contribution of Systems Engineering Approaches in Modeling Effectiveness

9.1. Assessment of the Role of Systems Engineering in Designing and Optimizing Safety Monitoring Systems

Systems engineering ensures that all system pieces function together to accomplish the desired objectives. In safety monitoring systems, this involves understanding stakeholder needs and expectations, defining system requirements, and creating a system design that integrates all necessary components [58]. The approach also involves identifying and reducing potential hazards to ensure the system functions reliably and safely.

Many companies use systems engineering to build and deploy their IoT-based safety monitoring systems. The system met its aims thanks to clear stakeholder and system requirements. A well-built system design allowed efficient integration of IoT devices, sensors, and data processing components [59]. Risk assessment and prevention also improved system reliability and safety.

9.2. Essential Components for Practical Application and Use

Installation and widespread acceptance of IoT-based safety monitoring systems depend on several factors. To begin, research must understand the system and stakeholder needs. Designers must develop plans to meet each workplace's demands, considering risks, job duties, and workforce characteristics.

Secondly, the system architecture must be well-designed. It combines IoT devices, sensors, and data processors into a coherent system. It also makes the system scalable and flexible to adapt to workplace changes and technology advancements. Thirdly, risk management is crucial. This entails identifying and mitigating system-related risks. To ensure reliability, it needs regular system maintenance and software updates [60].

Successful adoption depends on end-user acceptance. Employees must trust that the technology will improve safety without infringing privacy and feel comfortable using it. This requires honest communication about the system's aims, capabilities, and data protection. Systems engineering is essential for designing and optimizing IoT-based safety monitoring systems [61]. This role ensures project success. Companies can maximize these systems' effectiveness in increasing workplace safety by using a holistic strategy considering all system features and contexts.

10. Conclusions

10.1. Summary of Findings

In conclusion, evidence suggests that these solutions enabled real-time hazard identification, provided actionable worker health insights, and enhanced operational efficiency.

Systems engineering helped design and improved these systems. The successful design, deployment, and operation of these systems required a thorough understanding of stakeholder needs, a precise specification of system requirements, rugged system architecture design, and rigorous risk assessment and mitigation.

Despite their benefits, IoT-based solutions are limited. Overuse of technology can cause system failures, and insecure management of employee medical records is a concern. They must be part of a comprehensive safety management strategy to be successful.

10.2. General Industry Employee Health and Safety Consequences

Research investigation improves worker safety in many industries. IoT–based safety monitoring solutions in business areas with high physical injury have unexplored potential. Real-time risk identification and health monitoring could improve safety and save lives. These technologies are not limited to high-risk industries. Fields with fewer visible threats can customize IoT-based devices for stress management and ergonomic augmentation.

Successful implementation requires careful attention to system architecture, risk management, and user acceptance. This emphasizes the need for systems engineering in planning, developing, and implementing complex systems.

10.3. IoT-Based Safety Monitoring System Research and Deployment Prospects

Future development and deployment of internet-of-things-based safety monitoring systems can take several paths. Researchers should focus on improving system dependability and exploring new applications in several business areas. Studies show that addressing these systems' technological glitches and privacy issues is necessary.

Businesses should prioritize integrating these technologies into their safety management plan, customizing the system's architecture and functionality to their operations. Routine maintenance and updates and ample room for future technological advances ensure the systems' dependability.

Open communication and strict data protection should also focus on increasing user approval. The goal should be a safe, healthy, and respectful workplace. To conclude, systems engineering-supported IoT safety monitoring solutions can increase workplace safety. These solutions could usher in a new safety management era if consistently researched and improved.

Conflicts of Interest

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

References

[1] Teymourian, K. (2021) Integrating Ergonomics in Maintainability Design Process. Doctoral Dissertation, Luleå University of Technology.

[2] Tamrin, S.B.M. and Yusoff, I.M. (2014) 1 Hazards in Workplace. In: Bahri, S., *et al*., Eds., Occupational Safety and Health in Commodity Agriculture: Case Studies from Malaysian Agricultural Perspective, University Putra Malaysia, 55.

[3] Subhan, F., Mirza, A., Su'ud, M.B.M., Alam, M.M., Nisar, S., Habib, U., *et al*. (2023) AI-Enabled Wearable Medical Internet of Things in Healthcare System: A Survey. *Applied Sciences*, **13**, Article No. 1394. https://doi.org/10.3390/app13031394

[4] OSHA (2022) Top 10 Most Frequently Cited Standards. U.S. Department of Labor. https://www.osha.gov/top10citedstandards

[5] Le Er, B. and Wang, P. (2020) Service Composition Mechanism of Internet of Things. In: Hung, J.C., Yen, N.Y. and Chang, J.-W., Eds., *Frontier Computing*: *Theory*, *Tech-*

nologies and Applications, Springer, 1198-1204. https://doi.org/10.1007/978-981-15-3250-4_153

[6] eCampusOntario (n.d.) Hazard Recognition. https://ecampusontario.pressbooks.pub/cdnhealthsafetyworkplacefundamentals/chapter/3-3-hazard-recognition/

[7] Zolnikov, T.R., da Silva, R.C., Tuesta, A.A., Marques, C.P. and Cruvinel, V.R.N. (2018) Ineffective Waste Site Closures in Brazil: A Systematic Review on Continuing Health Conditions and Occupational Hazards of Waste Collectors. *Waste Management*, **80**, 26-39. https://doi.org/10.1016/j.wasman.2018.08.047

[8] Mariawati, A.S., Herlina, L. and Umyati, A. (2021) Analysis of Potential Risk Hazard with the HIRA and HAZOP Approach (Case Study: Laboratory of Engineering Faculty, Universitas Sultan Ageng Tirtayasa). *International Journal of Innovative Science and Research Technology*, **6**, 634-642.

[9] U.S. Bureau of Labor Statistics (BLS) (2022) Census of Fatal Occupational Injuries (CFOI), Fatal Occupational Injuries by Event or Exposure, 2017-2021. U.S. Department of Labor.

[10] Choi, S.D., Guo, L., Kim, J. and Xiong, S. (2019) Comparison of Fatal Occupational Injuries in Construction Industry in the United States, South Korea, and China. *International Journal of Industrial Ergonomics*, **71**, 64-74. https://doi.org/10.1016/j.ergon.2019.02.011

[11] Choi, Y., Kim, H.J., Sohn, J.R. and Seo, J.H. (2023) Occupational Exposure to Vocs and Carbonyl Compounds in Beauty Salons and Health Risks Associated with It in South Korea. *Ecotoxicology and Environmental Safety*, **256**, Article ID: 114873. https://doi.org/10.1016/j.ecoenv.2023.114873

[12] Dalyan, O., Özkaya, N., Pişkin, M. and Öztürk, Ö.F. (2021) Investigation and Comparison of Some Laboratories in Terms of Occupational Health and Safety by ELMERI Observation Method. *Journal of Advanced Research in Natural and Applied Sciences*, **7**, 282-294. https://doi.org/10.28979/jarnas.903664

[13] Fisher, T. and Gibson, T. (2008) A Measure of University Employees' Exposure to Risk Factors for Work-Related Musculoskeletal Disorders. *AAOHN Journal*, **56**, 107-114. https://doi.org/10.3928/08910162-20080301-05

[14] National Safety Council (2019) Injury Facts: Work-Related Injury Costs, 2019.

[15] Muluneh, A.G., Adem, K.S., Dawud, J.S., Kibret, A.K., Yitayal, M.M. and Eriku, G.A. (2022) Upper-Extremity Musculoskeletal Disorders and Their Associated Factors among Diabetes Mellitus Patients Attending at Felege Hiwot Comprehensive Specialized Hospital, Bahir Dar, Northwest Ethiopia: Cross-Sectional Study. *Frontiers in Endocrinology*, **13**, Article ID: 856521. https://doi.org/10.3389/fendo.2022.856521

[16] Leso, V., Fontana, L. and Iavicoli, I. (2018) The Occupational Health and Safety Dimension of Industry 4.0. *La Medicina del Lavoro*, **109**, 327-338. https://doi.org/10.23749/mdl.v109i5.7282

[17] Park, J., Kim, K. and Cho, Y.K. (2017) Framework of Automated Construction-Safety Monitoring Using Cloud-Enabled BIM and BLE Mobile Tracking Sensors. *Journal of Construction Engineering and Management*, **143**, Article ID: 05016019. https://doi.org/10.1061/(asce)co.1943-7862.0001223

[18] Kimani, K., Oduol, V. and Langat, K. (2019) Cyber Security Challenges for IoT-Based Smart Grid Networks. *International Journal of Critical Infrastructure Protection*, **25**, 36-49. https://doi.org/10.1016/j.ijcip.2019.01.001

[19] Häikiö, J., Kallio, J., Mäkelä, S. and Keränen, J. (2020) IoT-Based Safety Monitoring from the Perspective of Construction Site Workers. *International Journal of Occupational and Environmental Safety*, **4**, 1-14. https://doi.org/10.24840/2184-0954_004.001_0001

[20] Shrivastava, P. and Vidhi, R. (2020) Pathway to Sustainability in the Mining Industry: A Case Study of Alcoa and Rio Tinto. *Resources*, **9**, Article No. 70. https://doi.org/10.3390/resources9060070

[21] AL-Sahar, F., Przegalińska, A. and Krzemiński, M. (2021) Risk Assessment on the Construction Site with the Use of Wearable Technologies. *Ain Shams Engineering Journal*, **12**, 3411-3417. https://doi.org/10.1016/j.asej.2021.04.006

[22] Shapira, A., *et al.* (2018) Construction Planning, Equipment, and Methods. McGraw-Hill Education.

[23] Chander, B., Pal, S., De, D. and Buyya, R. (2022) Artificial Intelligence-Based Internet of Things for Industry 5.0. In: Pal, S., De, D. and Buyya, R., Eds., *Artificial Intelligence-Based Internet of Things Systems*, Springer International Publishing, 3-45. https://doi.org/10.1007/978-3-030-87059-1_1

[24] Driscoll, P.J., Parnell, G.S. and Henderson, D.L. (2022) Decision Making in Systems Engineering and Management. John Wiley & Sons.

[25] Lin, Y.-F., (2022) IoT for Environmental Management and Security Governance: An Integrated Project in Taiwan Region. *Sustainability*, **14**, Article No. 217. https://www.mdpi.com/2071-1050/14/1/217

[26] Díaz, M., Martín, C. and Rubio, B. (2016) State-of-the-Art, Challenges, and Open Issues in the Integration of Internet of Things and Cloud Computing. *Journal of Network and Computer Applications*, **67**, 99-117. https://doi.org/10.1016/j.jnca.2016.01.010

[27] Buede, D.M. and Miller, W.D.(2016) The Engineering Design of Systems: Models and Methods.

[28] Steingartner, W., Galinec, D. and Kozina, A. (2021) Threat Defense: Cyber Deception Approach and Education for Resilience in Hybrid Threats Model. *Symmetry*, **13**, Article No. 597. https://doi.org/10.3390/sym13040597

[29] Thibaud, M., Chi, H., Zhou, W. and Piramuthu, S. (2018) Internet of Things (IoT) in High-Risk Environment, Health and Safety (EHS) Industries: A Comprehensive Review. *Decision Support Systems*, **108**, 79-95. https://doi.org/10.1016/j.dss.2018.02.005

[30] Wang, L., Törngren, M. and Onori, M. (2015) Current Status and Advancement of Cyber-Physical Systems in Manufacturing. *Journal of Manufacturing Systems*, **37**, 517-527. https://doi.org/10.1016/j.jmsy.2015.04.008

[31] Andrade, R., Moazeni, S. and Ramirez-Marquez, J.E. (2019) A Systems Perspective on Contact Centers and Customer Service Reliability Modeling. *Systems Engineering*, **23**, 221-236. https://doi.org/10.1002/sys.21526

[32] Shin, D., Aliaga, D., Tunçer, B., Arisona, S.M., Kim, S., Zünd, D., *et al.* (2015) Urban Sensing: Using Smartphones for Transportation Mode Classification. *Computers, Environment and Urban Systems*, **53**, 76-86. https://doi.org/10.1016/j.compenvurbsys.2014.07.011

[33] Lameche, K., Najid, N.M., Castagna, P. and Kouiss, K. (2017) Modularity in the Design of Reconfigurable Manufacturing Systems. *IFAC-PapersOnLine*, **50**, 3511-3516. https://doi.org/10.1016/j.ifacol.2017.08.939

[34] Madni, A.M., Madni, C.C. and Lucero, S.D. (2019) Leveraging Digital Twin Technol-

ogy in Model-Based Systems Engineering. *Systems*, **7**, Article No. 7. https://doi.org/10.3390/systems7010007

[35] Yang, T., Xie, D., Li, Z. and Zhu, H. (2017) Recent Advances in Wearable Tactile Sensors: Materials, Sensing Mechanisms, and Device Performance. *Materials Science and Engineering*: *R*: *Reports*, **115**, 1-37. https://doi.org/10.1016/j.mser.2017.02.001

[36] Srinivas, T., Mahalaxmi, G., Varaprasad, R. and Raziya, D. (2022) A Comprehensive Survey of Techniques, Applications, and Challenges in Deep Learning: A Revolution in Machine Learning. *International Journal of Mechanical Engineering*, **7**, 286-296.

[37] MDPI (2020) Smart Helmet 5.0 for Industrial Internet of Things Using Artificial Intelligence. *Sensors*, **20**, Article No. 6241. https://www.mdpi.com/1424-8220/20/21/6241

[38] Amaraweera, S.P. and Halgamuge, M.N. (2019) Internet of Things in the Healthcare Sector: Overview of Security and Privacy Issues. In: Mahmood, Z., Ed., *Security*, *Privacy and Trust in the IoT Environment*, Springer International Publishing, 153-179. https://doi.org/10.1007/978-3-030-18075-1_8

[39] Barona, R. and Anita, E.A.M. (2017) A Survey on Data Breach Challenges in Cloud Computing Security: Issues and Threats. 2017 *International Conference on Circuit*, *Power and Computing Technologies* (*ICCPCT*), Kollam, 20-21 April 2017, 1-8. https://doi.org/10.1109/iccpct.2017.8074287

[40] Sadgrove, K. (2016) The Complete Guide to Business Risk Management. Routledge.

[41] Puli, L., Layton, N., Mont, D., Shae, K., Calvo, I., Hill, K.D., *et al*. (2021) Assistive Technology Provider Experiences during the COVID-19 Pandemic. *International Journal of Environmental Research and Public Health*, **18**, Article No. 10477. https://doi.org/10.3390/ijerph181910477

[42] DiMase, D., Collier, Z.A., Heffner, K. and Linkov, I. (2015) Systems Engineering Framework for Cyber Physical Security and Resilience. *Environment Systems and Decisions*, **35**, 291-300. https://doi.org/10.1007/s10669-015-9540-y

[43] Melcher, V., Diederichs, F., Maestre, R., Hofmann, C., Nacenta, J., van Gent, J., *et al*. (2015) Smart Vital Signs and Accident Monitoring System for Motorcyclists Embedded in Helmets and Garments for Advanced Ecall Emergency Assistance and Health Analysis Monitoring. *Procedia Manufacturing*, **3**, 3208-3213. https://doi.org/10.1016/j.promfg.2015.07.871

[44] Pramanik, P.K.D., Upadhyaya, B.K., Pal, S. and Pal, T. (2019) Internet of Things, Smart Sensors, and Pervasive Systems: Enabling Connected and Pervasive Healthcare. In: Dey, N., *et al*., Eds., *Healthcare Data Analytics and Management*, Elsevier, 1-58. https://doi.org/10.1016/b978-0-12-815368-0.00001-4

[45] Pandian, P.S., Mohanavelu, K., Safeer, K.P., Kotresh, T.M., Shakunthala, D.T., Gopal, P., *et al*. (2008) Smart Vest: Wearable Multi-Parameter Remote Physiological Monitoring System. *Medical Engineering & Physics*, **30**, 466-477. https://doi.org/10.1016/j.medengphy.2007.05.014

[46] Montanaro, T., Sergi, I., Motroni, A., Buffi, A., Nepa, P., Pirozzi, M., *et al*. (2022) An IoT-Aware Smart System Exploiting the Electromagnetic Behavior of UHF-RFID Tags to Improve Worker Safety in Outdoor Environments. *Electronics*, **11**, Article No. 717. https://doi.org/10.3390/electronics11050717

[47] Cheng, Q., *et al*. (2009) ZigBee Based Intelligent Helmet for Coal Miners. 2009 *WRI World Congress on Computer Science and Information Engineering*, Vol. 3, 433-435. https://doi.org/10.1109/csie.2009.653

[48] Choi, Y. and Kim, Y. (2021) Applications of Smart Helmet in Applied Sciences: A

Systematic Review. *Applied Sciences*, **11**, Article No. 5039.
https://doi.org/10.3390/app11115039

[49] Shu, L. and Li, X. (n.d.) A Smart Helmet for Network-Level Early Warning in Hazardous Environments.
https://www.semanticscholar.org/paper/A-smart-helmet-for-network-level-early-warning-in-Shu-Li/43f4b62090f3153c9aa3282bcc4d80ef50031c57

[50] Forsyth, J.B., Martin, T.L., Young-Corbett, D. and Dorsa, E. (2012) Feasibility of Intelligent Monitoring of Construction Workers for Carbon Monoxide Poisoning. *IEEE Transactions on Automation Science and Engineering*, **9**, 505-515.
https://doi.org/10.1109/tase.2012.2197390

[51] Patel, V., Chesmore, A., Legner, C.M. and Pandey, S. (2021) Trends in Workplace Wearable Technologies and Connected-Worker Solutions for Next-Generation Occupational Safety, Health, and Productivity. *Advanced Intelligent Systems*, **4**, Article ID: 2100099. https://doi.org/10.1002/aisy.202100099

[52] Lee, H. and Baek, K. (2021) Developing a Smart Multifunctional Outdoor Jacket with Wearable Sensing Technology for User Health and Safety. *Multimedia Tools and Applications*, **80**, 32273-32310. https://doi.org/10.1007/s11042-021-11166-7

[53] Casselman, J., Onopa, N. and Khansa, L. (2017) Wearable Healthcare: Lessons from the Past and a Peek into the Future. *Telematics and Informatics*, **34**, 1011-1023.
https://doi.org/10.1016/j.tele.2017.04.011

[54] Venkatesh, D.A.N. (2017) Connecting the Dots: Internet of Things and Human Resource Management. *American International Journal of Research in Humanities, Arts and Social Sciences*, **17**, 21-24.

[55] Márquez-Sánchez, S., Campero-Jurado, I., Herrera-Santos, J., Rodríguez, S. and Corchado, J.M. (2021) Intelligent Platform Based on Smart PPE for Safety in Workplaces. *Sensors*, **21**, Article No. 4652. https://doi.org/10.3390/s21144652

[56] Mejia, C., Ciarlante, K. and Chheda, K. (2021) A Wearable Technology Solution and Research Agenda for Housekeeper Safety and Health. *International Journal of Contemporary Hospitality Management*, **33**, 3223-3255.
https://doi.org/10.1108/ijchm-01-2021-0102

[57] Yang, P., Xiong, N. and Ren, J. (2020) Data Security and Privacy Protection for Cloud Storage: A Survey. *IEEE Access*, **8**, 131723-131740.
https://doi.org/10.1109/access.2020.3009876

[58] Li, R., Verhagen, W.J.C. and Curran, R. (2020) A Systematic Methodology for Prognostic and Health Management System Architecture Definition. *Reliability Engineering & System Safety*, **193**, Article ID: 106598.
https://doi.org/10.1016/j.ress.2019.106598

[59] Malik, N., Alkhatib, K., Sun, Y., Knight, E. and Jararweh, Y. (2021) A Comprehensive Review of Blockchain Applications in Industrial Internet of Things and Supply Chain Systems. *Applied Stochastic Models in Business and Industry*, **37**, 391-412.
https://doi.org/10.1002/asmb.2621

[60] Jardine, A.K.S. and Tsang, A.H.C. (2021) Maintenance, Replacement, and Reliability: Theory and Applications. 3rd Edition, CRC Press.
https://doi.org/10.1201/9780429021565

[61] Wortmann, F. and Flüchter, K. (2015) Internet of Things: Technology and Value Added. *Business & Information Systems Engineering*, **57**, 221-224.
https://doi.org/10.1007/s12599-015-0383-3