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**Sam Houston
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Insights and Recommendations**

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Abstract

Critical infrastructure sectors face growing risks from evolving threats such as cybersecurity attacks, natural disasters and cascading disruptions. Frontline employees play a pivotal role in mitigating these risks and ensuring operational continuity. However, limited research exists on the adequacy of training strategies tailored to the needs of small and medium-sized enterprises (SMEs) within these sectors. This study addresses this gap by examining existing workforce training approaches and highlighting opportunities for SMEs to enhance workforce training. The research employed a systematic literature review to evaluate current workforce training strategies. Relevant academic journals, industry publications and government reports were identified using targeted search terms such as “workforce training,” “critical infrastructure,” “SMEs” and sector-specific phrases like “energy sector workforce training,” “cybersecurity workforce training,” and “resilience training for SMEs.” Databases including Scopus, Web of Science, and Google Scholar served as primary sources. Six strategies were identified in this review: (1) traditional and core skills training, (2) technology integration and innovation training, (3) emerging threats and risk management training, (4) certification and regulatory compliance training, (5) partnerships with educational institutions and (6) simulation-based and virtual training. This study provides a unique perspective by focusing on the workforce training needs of SMEs within critical infrastructure sectors, an area often overlooked in broader industry discussions. By proposing tailored opportunities for SMEs, the research offers actionable insights that align with the resource constraints and operational challenges faced by smaller organizations.

Keywords: Critical infrastructure, Frontline employees, Resilience education, Risk mitigation, Scenario-based simulations, Training strategies, Workforce preparedness.

1. Introduction

Critical infrastructure is defined by the Department of Homeland Security's Cybersecurity and Infrastructure Security Agency (CISA) as the systems and assets that are so vital to the United States that their incapacity or destruction would have a debilitating effect on national security, the economy, public health, or safety (CISA,2022). This encompasses 16 critical infrastructure sectors, including Chemical, Commercial Facilities, Communications, Critical Manufacturing, Dams, Defense Industrial Base, Emergency Services, Energy, Financial Services, Food and Agriculture, Government Facilities, Healthcare and Public Health, Information Technology, Nuclear Reactors, Materials and Waste, Transportation Systems and Water and Wastewater Systems. According to Dawson *et al.*, (2021), these sectors are responsible for ensuring the daily functioning of society and maintaining the stability and security of the nation. The protection and resilience of critical infrastructure are therefore vital to safeguarding public health and the economy, as well as ensuring national security.

With the growing interdependencies across these sectors, the risks faced by critical infrastructure are also expanding. These risks include natural disasters, cybersecurity threats, terrorism and pandemics (Olonilua, 2022). As such, the workforce within these sectors is increasingly recognized as a key element in ensuring operational continuity and resilience during times of crisis. As Remington *et al.*, (2024) note, frontline employees are often the first responders to crises, whether they involve natural disasters, cyberattacks, or other disruptions. As such, they must be equipped with the skills and knowledge necessary to address and mitigate risks, maintain operations and protect public safety. For example, the 2021 Texas winter storm demonstrated the vulnerability of the state's energy infrastructure, with widespread power outages and water supply disruptions (Doss-Gollin *et al.*, 2021). The response to this disaster highlighted gaps in preparedness, particularly regarding workforce training in dealing with extreme weather events. Similarly, the rise in cyberattacks targeting critical infrastructure systems, such as the 2020 SolarWinds hack, underscores the need for workforce readiness to handle cybersecurity threats (Willett, 2023).

Despite the critical role played by frontline employees in ensuring the resilience of critical infrastructure, there are significant challenges related to workforce readiness and skill gaps. These challenges are especially pronounced in small to medium-sized enterprises (SMEs), which often face resource constraints and lack access to advanced training programs (Chuang, 2024). A major issue is the inadequacy of existing workforce training strategies, which often focus primarily on technical skills without addressing the broader needs of crisis management and decision-making under pressure (Cubrich *et al.*, 2022). According to Remington *et al.*, (2024), the evolving nature of threats, such as the increasing frequency and severity of cyberattacks and the impacts of climate change, has created an urgent need for more wide-ranging workforce training programs. For example, many employees in critical infrastructure sectors may be well-versed in routine tasks but may not be adequately trained to respond to large-scale emergencies or to handle complex, multi-faceted crises (Chuang, 2024). The skills gap can result in inefficiencies, slow response times, and, in the worst cases, failures to prevent or mitigate disasters.

Another challenge is the disparity in training resources between large corporations and SMEs. While large organizations can often invest in advanced training technologies, such as scenario-based simulations and virtual training platforms (Sanchez *et al.*, 2023), SMEs often struggle to access these resources. As a result, many frontline employees in smaller organizations are left with outdated or generic training that does not address the unique needs of their specific sector or region. For example, energy sector employees may have training focused on maintaining power lines but may not receive adequate education on responding to cyberattacks targeting the energy grid. Similarly, healthcare workers may be trained for routine procedures but lack crisis management training for pandemics or large-scale natural disasters. These training gaps contribute to vulnerabilities in critical infrastructure systems, especially during emergencies.

Therefore, the main objective of this study is to explore the current workforce training strategies within critical infrastructure sectors, with a particular focus on SMEs. This study will focus on the energy, water, transportation and healthcare sectors, as these are among the most vital to public safety and the economy. The study will then propose actionable recommendations to enhance workforce training strategies for SMEs within these sectors. This study will not only contribute to academic knowledge but also offer actionable insights for policymakers, industry leaders and

educational institutions to foster stronger collaborations and enhance the training capabilities of SMEs in these key sectors.

2. Related Work

Based on the authors' knowledge, a systematic literature review that examines workforce training strategies within critical infrastructure sectors, particularly focusing on SMEs, has not been conducted yet. While there have been numerous studies on the general importance of workforce training in critical infrastructure, the literature primarily addresses large organizations and does not fully explore the unique challenges faced by SMEs, which are often constrained by limited resources. Several studies have highlighted the significance of workforce preparedness in critical infrastructure sectors such as energy, water, transportation and healthcare. One significant body of research focuses on workforce training in the energy sector, particularly in response to the increasing complexity of the industry. Gurieiev *et al.*, (2020) examined the importance of continuous training for energy sector employees, emphasizing the need for ongoing education due to the rapid technological advancements and the growing sophistication of cybersecurity threats. With energy systems becoming increasingly interconnected and dependent on digital infrastructure (Jasiūnas *et al.*, 2021), traditional training programs are no longer sufficient. The authors argue for the implementation of dynamic, ongoing training models that equip employees with the latest skills and knowledge to address both technical challenges and cyber threats. Furthermore, they highlight the lack of training opportunities for SMEs in the energy sector, which are often overlooked in larger-scale initiatives, despite their critical role in ensuring the resilience of the energy supply chain (Jasiūnas *et al.*, 2021),

Similarly, Bekiaris and Loukea (2019) studied workforce training in the transportation sector, emphasizing the importance of safety protocols and emergency response training for frontline workers. Their research underscores the role of specialized training programs in mitigating the risks associated with transportation accidents and ensuring quick, effective responses in emergencies. The authors discuss the complexity of training programs designed for the transportation workforce, noting that training methods such as simulation-based learning and scenario exercises are highly effective in enhancing employee preparedness (Bekiaris and Loukea, 2019). However, they also point out that SMEs within the transportation sector face significant hurdles in providing such advanced training methods, primarily due to financial and resource

constraints. This gap in training availability and access to state-of-the-art learning technologies presents a challenge for smaller organizations attempting to maintain workforce readiness (Ambra *et al.*, 2019). The concept of resilience and its integration into workforce training is another area where substantial research has been conducted. Heath *et al.*, (2020) explored resilience education, specifically how training programs can improve both technical skills and decision-making abilities of employees during crises. Their work highlights the importance of training programs that go beyond conventional skills development and focus on equipping workers with the cognitive tools needed to manage high-stress, high-risk situations. This approach, known as resilience education, has been shown to improve operational continuity during disruptions (Heath *et al.*, 2020). Although their study emphasizes the role of resilience in large organizations, the authors also acknowledge that SMEs could benefit from resilience-based training, especially as they often operate under heightened pressure during emergencies. However, the resource limitations of SMEs make it difficult for them to implement these advanced training methodologies effectively.

3. Research Methodology

This study adopted an eight-step approach for literature review based on the framework proposed by Okoli and Schabram (2015). The process was systematically structured to ensure that relevant studies were identified, assessed and synthesized. The eight steps are listed below and discussed further:

1. Defining the objective of the review
2. Protocol development
3. Conducting a comprehensive literature search
4. Screening for relevance
5. Assessing the quality of the selected studies
6. Extracting data from the studies
7. Synthesizing the findings from the studies
8. Writing the review

3.1. Defining the Objective of the Review

The primary aim of this literature review is to examine the current workforce training strategies within critical infrastructure sectors, with a specific focus on SMEs. These sectors (energy, water,

transportation and healthcare) are integral to public safety and the economy, making workforce preparedness crucial. The following points describe the specific objectives of this study:

- To explore the existing workforce training strategies within critical infrastructure sectors (energy, water, transportation and healthcare) with a focus on SMEs.
- To propose actionable recommendations to enhance workforce training strategies for SMEs in these sectors.
- To contribute to both academic knowledge and practical solutions to strengthen the workforce in critical sectors.

3.2. Protocol Development

This step involves developing a review protocol that aligns with the study's objectives. Okoli and Schabram's (2015) approach was selected due to its systematic and structured methodology, which ensures a consistent and transparent process for conducting a literature review. The protocol for this study outlines key aspects such as the inclusion and exclusion criteria, specific focus areas (e.g., SMEs within critical infrastructure sectors like energy, water, transportation and healthcare) and the methodologies for evaluating relevant studies. By clearly defining the boundaries of the review, the protocol ensures that only studies directly related to workforce training strategies in SMEs are included, providing a focused and relevant body of literature for analysis.

3.3. Conducting a Comprehensive Literature Search

The search covered a wide range of databases, including Scopus, Web of Science, Google Scholar, IEEE Xplore, ScienceDirect, JSTOR, PubMed, SpringerLink, ProQuest and Emerald Insight. These databases were chosen for their broad coverage of relevant topics such as energy, transportation, healthcare and workforce training. A combination of keywords was used to ensure comprehensive coverage of the topic, including terms like "workforce training," "critical infrastructure," "SMEs" and sector-specific phrases like "energy sector workforce training," "cybersecurity workforce training," and "resilience training for SMEs." The search string used was: ("workforce training" AND "critical infrastructure" AND "SMEs" AND ("energy" OR "transportation" OR "healthcare" OR "water") AND ("cybersecurity" OR "disaster preparedness" OR "resilience")). This search resulted in 875 articles. After screening for relevance based on inclusion and exclusion criteria, and removing duplicates, 127 articles remained for further review.

Non-relevant articles, including those that did not directly address SMEs or workforce training in critical infrastructure sectors, were omitted.

3.4. Screening for Relevance

In this step, the identified articles were screened for relevance based on specific inclusion and exclusion criteria that aligned with the study's objectives. The inclusion and exclusion criteria are outlined below:

Inclusion criteria:

1. Only peer-reviewed articles published in reputable journals or conferences were considered.
2. Studies that specifically addressed workforce training strategies within critical infrastructure sectors, particularly for SMEs.
3. Articles that discussed issues such as cybersecurity, disaster preparedness, resilience, or other emerging threats pertinent to the energy, water, transportation, or healthcare sectors.
4. Preference was given to studies providing practical insights or case studies on training programs for SMEs within these sectors.

Exclusion criteria:

1. Studies that did not specifically address workforce training or focused solely on large organizations without relevance to SMEs.
2. Articles that lacked empirical data or presented only theoretical models without practical applications.
3. Studies published before 2010, as they may not reflect current practices and challenges.
4. Non-English language articles were excluded due to language proficiency limitations.

This screening process resulted in narrowing down the initial 127 articles to 84 articles that met the inclusion criteria. These 84 articles were then analyzed in detail to extract data that could contribute to the study's understanding of workforce training strategies in critical infrastructure sectors, with a specific focus on SMEs.

3.5. *Assessing the Quality of the Selected Studies*

In this step, the quality of the selected studies was carefully assessed to ensure that the findings were credible and relevant to the research objectives. The assessment aimed to determine the reliability, validity and methodological rigor of the studies included in the review. To achieve this, a set of predefined criteria was applied to evaluate each study's methodological approach, data collection methods, analysis techniques and overall contribution to the understanding of workforce training strategies within critical infrastructure sectors, particularly focusing on SMEs. The quality assessment process involved examining several key factors. First, the methodological rigor was evaluated, considering whether the studies employed appropriate research designs such as case studies, surveys, or experiments. Studies with clear and well-structured methodologies were given higher weight. Second, the sampling strategy used in the studies was assessed. Studies that included diverse samples from SMEs within the critical infrastructure sectors were preferred, as these would provide a broader understanding of workforce training strategies across different contexts. Third, the clarity and transparency of data collection and analysis processes were examined, ensuring that the studies provided sufficient detail on how data was gathered, analyzed, and interpreted. Additionally, the relevance of the findings to the research objectives was critically evaluated. Studies that directly addressed the challenges SMEs face in workforce training, such as resource constraints or sector-specific threats, were prioritized. Peer-reviewed articles published in reputable journals were considered more reliable than conference papers or grey literature. The quality assessment process resulted in retaining 42 studies that met the high standards for inclusion, ensuring that the literature used in the review was of sufficient quality to support the study's objectives.

3.6. *Extracting Data from the Studies*

In this step, relevant data was systematically extracted from the selected studies to address the research objectives, focusing on workforce training strategies within critical infrastructure sectors, particularly for SMEs. The data extraction process involved identifying key information such as study characteristics (e.g., author, year, sector), training methods used, challenges faced by SMEs, and the effectiveness of the training programs. To ensure consistency, a standardized data extraction form was developed and organized into a table with eight columns, each representing key attributes necessary to summarize and assess the relevance of the studies. These attributes

included details like training strategies, challenges, outcomes and gaps in workforce preparedness. This structured approach facilitated the comparison of findings across sectors and enabled the synthesis of the evidence.

3.7. *Synthesis of Studies*

In the synthesis of studies, the extracted data was analyzed and combined to address the research objectives, highlighting patterns, trends and insights related to workforce training. The synthesis process involved grouping the studies based on common themes, such as training methods, challenges faced by SMEs and the effectiveness of training programs in enhancing workforce preparedness. Comparative analysis was conducted across the five sectors to identify similarities and differences in workforce training approaches. The findings were synthesized to provide a holistic understanding of the existing strategies and their relevance to SMEs, ultimately informing the study's recommendations for improving workforce training in critical infrastructure sectors. This synthesis allowed for a clearer picture of how training programs can be optimized, especially within resource-constrained environments like SMEs.

3.8. *Writing the Review*

The process of writing this systematic literature review was conducted in line with the established guidelines for writing research articles, following the methodology outlined by Okoli and Schabram (2015). After the initial search, a total of 875 articles were retrieved using the combination of keywords indicated in Section 3.3. This large number of results was partly due to the absence of effective filters in many of the database search engines based on the previously defined inclusion and exclusion criteria. After two rounds of practical screening, in which articles that did not meet the requirements outlined in Section 3.4 were removed, the selection was reduced to 127 articles. These articles were then further manually reviewed to ensure their relevance to the subject of the review. The manual screening involved eliminating articles that did not reference the key themes or keywords mentioned in Section 3.3. Simultaneously, articles that did not meet the second rule of the quality appraisal discussed in Section 3.5 were also excluded. Following the quality appraisal process, the final selection consisted of 84 articles that contributed to the literature review, with an additional 42 studies being incorporated into the related work section.

4. Results and Discussion

4.1. Existing Workforce Training Strategies Within Critical Infrastructure Sectors

4.1.1. Traditional and Core Skills Training

Traditional and core skills training remain fundamental in ensuring the proper operation and safety of critical infrastructure systems. In the water sector, training often focuses on the foundational knowledge required for water treatment and distribution. For instance, large utilities such as the Los Angeles Department of Water and Power (LADWP) provide in-depth training on water purification, reservoir management and pipeline maintenance (LADWP, 2024). During these trainings, workers are taught hands-on how to handle critical equipment such as water treatment plants and chemical dosing systems. In the transportation sector, training often revolves around vehicle operation, safety protocols and regulatory compliance. One example is FedEx, which runs a comprehensive training program for its drivers to ensure they understand safety standards, regulatory requirements and customer service. Similarly, in the healthcare sector, traditional certifications such as Basic Life Support (BLS) and Advanced Cardiac Life Support (ACLS) ensure that healthcare professionals possess the core skills necessary to perform emergency medical procedures. For example, Mayo Clinic requires all medical personnel to undergo ACLS and BLS training regularly to maintain readiness in emergency situations (Mayo Clinic, 2021).

For SMEs, traditional and core skills training often takes a more focused approach, depending on the specific needs of the business. According to Perez *et al.*, (2016), smaller enterprises may not have the resources for extensive in-house training programs, so they often rely on third-party training providers or certification programs. In the water sector, for instance, small water utilities may not have the budget for large-scale training, so they often turn to American Water Works Association (AWWA) certification programs, which provide essential skills in water quality management, wastewater treatment and system maintenance (Olson, 2020). In healthcare SMEs, such as small clinics, the staff often relies on third-party certification courses like Basic Life Support (BLS) and Advanced Cardiovascular Life Support (ACLS) provided by the American Heart Association (AHA), ensuring they meet regulatory requirements and can respond to emergencies.

4.1.2. Technology Integration and Innovation Training

With rapid technological advancements, critical infrastructure sectors are evolving by integrating innovative tools and systems. In the water sector, technologies such as smart meters, automated leak detection and remote monitoring systems are revolutionizing utility operations. For instance, the City of Atlanta recently announced plans to utilize artificial intelligence (AI) to manage its aging water infrastructure. This decision comes in response to two significant water main breaks earlier this year. To prevent future incidents, AI-enhanced devices are being installed on water line valves at the affected locations. These devices will provide early warnings, allowing for proactive maintenance and more efficient infrastructure management (Smart Water, 2024). Atlanta's Smart Water Management System also incorporates automated leak detection sensors and real-time water quality monitoring. This technology enables the city to optimize water resource management, minimize losses, and ensure a safe, high-quality water supply. Mayor Andre Dickens highlighted these improvements as a critical step in modernizing the city's water infrastructure (Smart Water, 2024). In the transportation sector, the introduction of autonomous vehicles and AI-powered logistics platforms has driven companies to train their workforce in new technologies. For instance, Tesla provides training for its technicians on electric vehicle (EV) systems, battery technologies and software updates (Dreher *et al.*, 2024). In the healthcare sector, the adoption of technologies like robotic-assisted surgeries and telemedicine demands that healthcare workers constantly upskill. For example, Cleveland Clinic has developed training programs for surgeons to learn how to operate robotic systems for minimally invasive surgeries, allowing for greater precision and faster recovery times (Cleveland Clinic, 2023).

SMEs are also pushing to leverage these new technologies but often face challenges due to limited resources. According to Bradač Hojnik and Huđek (2023), smaller organizations often make use of affordable digital tools, training platforms and collaborations with larger institutions. In the water sector, small utilities are beginning to adopt smart metering systems and remote monitoring tools. For example, small municipal systems often partner with larger firms or universities to integrate IoT-based water management systems that help track consumption and detect leaks. For training, SMEs regularly rely on online platforms like Coursera or Udemy to educate employees about new tools and technology (Pawar and Lal, 2022). Similarly, smaller transportation companies also integrate telematics systems to monitor vehicle performance but may outsource

training on these systems to third-party providers that specialize in fleet management technologies (Dudin *et al.*, 2019). In healthcare, small clinics and private practices adopt technologies like telemedicine platforms but often need affordable and efficient training solutions, which could be obtained through partnerships with larger healthcare providers or certification bodies like the American Telemedicine Association (ATA).

4.1.3. Emerging Threats and Risk Management Training

Emerging threats, particularly cyberattacks and environmental crises, are reshaping the need for risk management training within critical infrastructure sectors. In the water sector, cyberattacks targeting water systems are a growing concern. For instance, a 2021 cyberattack on the Oldsmar, Florida water treatment facility highlighted the vulnerabilities of water utilities to cyber threats (Cervini *et al.*, 2022). In response, the American Water Works Association (AWWA) launched cybersecurity awareness programs aimed at water sector employees to prevent similar breaches. In the transportation sector, emerging risks related to autonomous vehicles and connected infrastructure require specialized cybersecurity training. For example, General Motors and Waymo have begun training their engineers to secure communication between self-driving cars and transportation networks (Chai, 2020). Additionally, airlines like Delta invest in risk management programs for pilots and crew to respond to unexpected challenges such as extreme weather conditions or system failures. In the healthcare sector, cybersecurity threats are also a growing concern. The Universal Health Services (UHS) ransomware attack in 2020 disrupted hospital operations which resulted in reported total pre-tax losses of an estimated \$67 million, highlighting the need for cybersecurity training (UHS, 2020). In response, the National Cybersecurity Center of Excellence (NCCoE) has collaborated with healthcare institutions to offer training in secure patient data handling and digital infrastructure protection.

SMEs are also vulnerable to cybersecurity and environmental threats due to limited resources. In the water sector, for example, small water utilities often do not have the in-house expertise to address cybersecurity risks, so they often rely on national training programs or partnerships with cybersecurity firms to ensure they protect their systems. The Cybersecurity and Infrastructure Security Agency (CISA) offers resources specifically geared toward smaller utilities to mitigate cybersecurity threats (CISA, 2022). Similarly, in the transportation sector, smaller companies often lack the cybersecurity budgets to create comprehensive protection protocols, so they utilize

external providers for cybersecurity training, including platforms like CISA. In healthcare, smaller practices or hospitals may also be targets for cyberattacks due to inadequate security systems. Following the 2020 Universal Health Services (UHS) attack, many small healthcare providers began looking for cost-effective ways to ensure their staff is trained in cyber hygiene and secure patient data management, with programs offered through entities like Health Information Trust Alliance (HITRUST) or the National Institute of Standards and Technology (NIST) (Sahid, 2024).

4.1.4. Certification and Regulatory Compliance Training

Certification and regulatory compliance are critical to maintaining standards and meeting legal requirements in critical infrastructure sectors. In the water sector, certifications from organizations like the Water Environment Federation (WEF) are essential for ensuring that employees are up to date on the latest environmental standards and operational procedures (Wahl, 2019). For example, the City of New York's Department of Environmental Protection (DEP) requires its employees to hold certifications in water treatment, distribution and wastewater management. In the transportation sector, regulatory compliance training is essential for ensuring vehicle safety and operational standards. For instance, in the aviation industry, the Federal Aviation Administration (FAA) mandates regular certification for pilots, air traffic controllers and maintenance technicians. Also, Delta Airlines has comprehensive training programs that include safety regulations, emergency response procedures and regulatory updates from the FAA (Gonczy, 2015). In the healthcare sector, regulatory training ensures that healthcare providers comply with both local and international healthcare standards. The Joint Commission regularly audits hospitals, and as part of compliance, staff undergo training on best practices, such as infection control and patient safety procedures. The American Heart Association (AHA) offers certification programs that are required for healthcare professionals working in emergency medical services (EMS), including paramedics and emergency room staff (AHA, 2022).

For SMEs, maintaining regulatory compliance is crucial, yet often challenging due to limited resources. However, many third-party certification programs cater to SMEs' needs in critical infrastructure sectors. In the water sector, small utilities typically rely on industry-standard certification programs from the AWWA or State Health Departments, which ensure their employees meet the legal requirements for water treatment and public health (Olson, 2020). In transportation, compliance training is a key part of SME workforce preparation, especially for

small logistics companies or delivery services. Programs from organizations like the Federal Motor Carrier Safety Administration (FMCSA) or OSHA are often utilized to train drivers and operational staff in essential regulatory standards such as driver hours-of-service rules and transportation of hazardous materials (Driving, 2020). In healthcare, small clinics and independent practices often focus on certifications for infection control, HIPAA compliance and OSHA regulations to ensure they meet legal standards and industry practices. The American Medical Association (AMA) and Centers for Medicare & Medicaid Services (CMS) provide resources that allow SMEs to comply with federal healthcare regulations while keeping their workforce well-trained (Rondinelli *et al.*, 2023).

4.1.5. Partnerships with Educational Institutions

Collaborations with academic institutions provide critical infrastructure sectors with advanced training programs and innovative research. In the water sector, partnerships with universities enable utilities to stay ahead in water management technologies. For example, The University of California, Berkeley has collaborated with Pacific Gas and Electric (PG&E) to develop training programs focused on sustainable water use and energy efficiency (University of California, 2024). Additionally, in the transportation sector, universities like the Massachusetts Institute of Technology (MIT) have worked with companies like Ford Motor Company and General Motors to advance the development of autonomous vehicle technologies. These partnerships involve research-driven training on AI, machine learning and system integration. In the healthcare sector, hospitals and universities partner to offer specialized programs on the latest medical technologies. For example, the Mayo Clinic partners with the University of Minnesota to provide specialized training in areas such as robotic surgeries, telemedicine, and advanced diagnostic imaging systems (University of Minnesota Rochester, 2022).

Likewise, SMEs also partner with universities or technical institutions to bridge the training gap caused by constrained resources. These partnerships may also include internship programs or joint research projects that help train staff while improving services. In the transportation sector, smaller companies in logistics often form partnerships with community colleges to provide ongoing driver safety and compliance training. An example is the Community College of Philadelphia, which partners with transportation companies to offer certification courses in commercial driving and logistics management (Aidoo, 2017). Similarly, in healthcare, small clinics and practices partner

with universities to offer training in specialized areas such as robotic surgery, telehealth services, or medical billing and coding, often through online learning platforms like Coursera or edX.

4.1.6. *Simulation-Based and Virtual Training*

Simulation-based and virtual training has become integral to preparing employees for real-world scenarios without the risks associated with live training. In the water sector, utilities like Los Angeles Water and Power (LADWP) use virtual simulation programs to train staff on handling emergencies such as flooding or contamination incidents. These simulations allow employees to practice decision-making in real-time without risking public safety (Zohrabian and Sanders, 2020). In the transportation sector, airlines like Southwest Airlines utilize flight simulators to train pilots and crew members for emergencies, ensuring they can respond effectively to any crisis. For example, pilots train for emergency scenarios like engine failure or severe weather in a highly controlled environment, improving their performance under pressure (Wei *et al.*, 2022). Similarly, rail operators use train simulators to train employees to handle track-related incidents or signaling issues safely (Patel *et al.*, 2023). In the healthcare sector, virtual patient simulators are widely used to train medical professionals in diagnostic procedures and emergency response. The University of California, San Francisco has implemented virtual reality (VR) simulations in medical training, allowing healthcare providers to interact with simulated patients to improve diagnostic and procedural skills (Malone *et al.*, 2024).

Simulation-based training and virtual platforms are particularly beneficial for SMEs, as they provide cost-effective ways to enhance skills without the need for expensive physical infrastructure. In the water sector, SMEs are increasingly adopting virtual simulation tools that allow their employees to practice responding to emergencies such as pipeline bursts or contamination without actual risk. For instance, eWater (Australia) offers virtual training programs designed for small utilities to learn about water treatment and emergency response (Chong *et al.*, 2017). In transportation, small delivery companies and freight firms can use virtual driving simulators to train their staff, cutting down on training costs and improving safety protocols. For healthcare SMEs, virtual patient simulators and telemedicine simulations are cost-effective training tools. For example, the University of California, San Francisco (UCSF) uses virtual patient

simulations for clinical staff to practice diagnostic and procedural skills, which smaller practices can access to upskill their workforce affordably (UCSF, 2024).

Table 1: Summary of Workforce Training Strategies in Critical Infrastructure Sectors

Training Strategy	Brief Description	Author(s)	Sectors
Traditional and Core Skills Training	<p>This encompasses foundational training programs that equip employees with the essential knowledge and skills necessary for their roles. This includes technical expertise in areas such as water treatment processes, energy production methods, and patient care protocols. Additionally, it covers core competencies crucial for effective job performance, such as:</p> <ul style="list-style-type: none"> - <i>Safety Training</i>: OSHA compliance, hazard recognition, emergency response procedures. - <i>Technical Skills</i>: Equipment operation and maintenance, troubleshooting, specialized skills relevant to specific roles (e.g., electrical, mechanical). - <i>Core Competencies</i>: Communication, teamwork, problem-solving, critical thinking, decision-making and adaptability. 	Gonecny (2015); Ambra <i>et al.</i> , (2019); Brown <i>et al.</i> , (2020); Gurieiev <i>et al.</i> , (2020); Blanchard <i>et al.</i> , (2023)	Energy, Water, Transportation, Healthcare
Technology Integration and Innovation Training	<p>This training focuses on equipping employees with the skills and knowledge to effectively utilize and adapt to emerging technologies that are rapidly transforming critical infrastructure sectors. This includes:</p> <ul style="list-style-type: none"> - <i>Cybersecurity Training</i>: Phishing awareness, incident response, data protection, and defense against cyber threats. - <i>Automation and Robotics Training</i>: Training on the operation and maintenance of automated systems, including robotics and AI-powered technologies. - <i>IoT Training</i>: Understanding and utilizing the Internet of Things (IoT) in infrastructure management, such as smart grid technologies, sensor networks and data analytics. 	Naranjo-Valencia <i>et al.</i> , (2018); Wahl (2019); Apa <i>et al.</i> , (2021); (Jasiūnas <i>et al.</i> , 2021); Sanchez <i>et al.</i> , (2023)	Energy, Water, Transportation, Healthcare
Emerging Threats and Risk Management Training	<p>This training prepares workers to identify, assess, and mitigate the impact of emerging threats and risks that can significantly impact critical infrastructure operations. This includes:</p> <ul style="list-style-type: none"> - <i>Threat Assessment</i>: Identifying potential threats such as natural disasters (e.g., earthquakes, floods), cyberattacks, pandemics, and terrorism. - <i>Risk Mitigation</i>: Developing and implementing strategies to reduce the likelihood and impact of these threats, such as emergency response plans, business continuity plans, and disaster recovery procedures. 	Ambra <i>et al.</i> , (2019); Brown <i>et al.</i> , (2020); Chai (2020); (Jasiūnas <i>et al.</i> , 2021); AHA (2022); Sanchez <i>et al.</i> , (2023)	Healthcare, Energy
Certification and Regulatory Compliance Training	<p>This training ensures that workers meet industry standards and comply with relevant regulations. This involves:</p> <ul style="list-style-type: none"> - <i>Industry Certifications</i>: Obtaining professional certifications relevant to their roles (e.g., electrician licenses, operator certifications) to demonstrate expertise and meet industry standards. - <i>Regulatory Compliance Training</i>: Training on relevant laws, regulations, and safety standards to ensure compliance with government regulations and industry best practices. This is particularly crucial in sectors like water, transportation and healthcare, which are subject to stringent regulations. 	Ambra <i>et al.</i> , (2019); Olson (2020); (Jasiūnas <i>et al.</i> , 2021); Blanchard <i>et al.</i> , (2023); Sanchez <i>et al.</i> , (2023)	Water, Transportation, Healthcare
Partnerships with Educational Institutions	<p>This involves collaborative efforts between industry and academia to enhance workforce development. Key initiatives include:</p> <ul style="list-style-type: none"> - <i>Apprenticeships and Internships</i>: Providing on-the-job training and mentorship opportunities for students, fostering practical skills and industry experience. 	Naranjo-Valencia <i>et al.</i> , (2018); Ambra <i>et al.</i> , (2019); Bekiaris and	Energy, Water, Transportation, Healthcare

	<ul style="list-style-type: none"> - <i>Joint Training Programs</i>: Developing and delivering specialized training programs in collaboration with universities and technical colleges, leveraging academic expertise and industry needs. - <i>Guest Lectures and Workshops</i>: Facilitating knowledge exchange by inviting industry professionals to speak at academic institutions and vice versa. 	Loukea (2019); Rondinelli <i>et al.</i> , (2023); Sanchez <i>et al.</i> , (2023)	
Simulation-Based and Virtual Training	<p>This leverages technology to create realistic training environments that replicate real-world scenarios, allowing employees to learn and practice skills in a safe and controlled setting. This includes:</p> <ul style="list-style-type: none"> - <i>Simulators</i>: Utilizing sophisticated simulators to replicate complex systems and scenarios, such as power plant simulators, flight simulators, and medical simulations. - <i>E-learning Platforms</i>: Providing online courses and training modules that offer flexibility and accessibility for employees. - <i>Virtual Reality (VR) Training</i>: Immersive training experiences that enhance learning and retention by providing a realistic and engaging environment for skill development. 	Bekiaris and Loukea (2019); Apa <i>et al.</i> , (2021); Elendu <i>et al.</i> , (2024); Sahid (2024)	Healthcare, Transportation, Energy

4.3. Workforce Training Challenges and Opportunities for SMEs in Critical Infrastructure Sectors

Small and medium-sized enterprises (SMEs) within critical infrastructure sectors face a unique set of challenges when it comes to workforce training. These challenges often stem from limited resources, both financial and human, as well as the complexity of meeting industry standards and regulatory requirements (Gamage *et al.*, 2020; Doss-Gollin *et al.*, 2021). One of the most significant challenges SMEs faces is limited financial resources, which makes it difficult for them to invest in comprehensive workforce training programs. Unlike large organizations, SMEs often do not have the budget for dedicated in-house training teams or advanced simulation tools (Dudin *et al.*, 2019; Pawar and Lal, 2022). This constraint can hinder their ability to implement strategies such as technology integration and innovation training (e.g., adopting AI or digital technologies) or simulation-based and virtual training (e.g., using virtual labs for emergency preparedness).

Another challenge is the lack of specialized expertise within SMEs. Many critical infrastructure sectors require a high level of technical knowledge, especially in areas like cybersecurity and regulatory compliance. According to Gurieiev *et al.*, (2020), SMEs often struggle to provide their employees with the necessary technical skills or to offer emerging threats and risk management training, particularly as they may not have dedicated cybersecurity experts in-house. Moreover, SMEs may find it difficult to keep up with evolving technologies and industry standards, such as

the certification and regulatory compliance training required in sectors like healthcare and transportation (Jasiūnas *et al.*, 2021). As discussed earlier, compliance with industry regulations is crucial for ensuring safety and operational efficiency. However, for SMEs, the complexity and cost of compliance training, particularly with constantly changing regulations, pose a significant burden (Shashidhar and Varol, 2023). For example, small water utilities may not have the resources to invest in extensive training programs required to meet the standards set by organizations like the American Water Works Association (AWWA). Similarly, in the healthcare sector, small clinics may struggle to keep their staff updated on the latest certification and regulatory compliance training required for infection control and patient safety protocols (Heath *et al.*, 2020).

4.4. Recommendations for Enhancing Workforce Training in SMEs

To enhance workforce training and development, SMEs can consider forming strategic partnerships with universities, technical institutions and industry associations (Apa *et al.*, 2021). Such collaborations provide access to cutting-edge research, specialized training programs and innovative technologies. For example, SMEs in sectors like water treatment and transportation could partner with local universities to access affordable or even subsidized training programs. The University of California, Berkeley, has formed partnerships with local SMEs in the clean energy sector, providing access to advanced research facilities and expertise in sustainable technologies (University of California, 2024). Similarly, the University of Nevada, Reno has partnered with local water utilities to focus on applied research in water and wastewater treatment technologies (Brown *et al.*, 2020). These partnerships not only enhance the technical capabilities of SMEs but also foster innovation and competitiveness within their industries.

Another opportunity for SMEs to enhance workforce training is through simulation-based and virtual training. These cost-effective solutions offer scalable ways to deliver high-quality training without the need for expensive physical setups. For example, small water utilities can use virtual training platforms to simulate emergencies, such as contamination or pipe bursts, allowing staff to practice their responses in a controlled environment (Sanchez *et al.*, 2023). In the healthcare sector, virtual patient simulators and telemedicine simulations can provide affordable and accessible training for small clinics, helping to improve diagnostic and procedural skills. These simulation-

based approaches allow SMEs to train their workforce efficiently while managing limited resources.

Lastly, flexible, modular training programs are a practical solution for SMEs with budget constraints. These programs allow businesses to tailor training to the specific needs of their workforce while providing the flexibility for employees to learn at their own pace. Programs that can be delivered online or in short bursts are particularly beneficial, as they enable SMEs to balance workforce development with financial limitations (Ambra *et al.*, 2019). For example, Stanford Online offers a digital transformation and technology integration program consisting of self-paced courses that professionals can complete over time. This model allows SMEs to keep their employees up to date with the latest technologies and digital strategies without the need for long-term, full-time training commitments. By embracing these training solutions, SMEs can enhance their workforce capabilities and remain competitive in an ever-evolving market (Cubrich *et al.*, 2022).

5. Practical Applicability of Findings

Having reviewed the various workforce training strategies, the findings provide actionable solutions that SMEs in the energy, water, transportation and healthcare sectors can adopt to address workforce preparedness gaps, improve resilience and enhance operational efficiency. One key strategy is targeted workforce development through partnerships with universities, technical institutions and industry associations. SMEs can leverage these collaborations to access tailored, affordable training programs that meet their workforce needs. For example, in the water sector, small utility companies could collaborate with universities to gain subsidized training in water treatment technologies and quality monitoring. The University of North Carolina's Environmental Finance Center has partnered with small utilities to deliver workshops and online training that build workforce capacity and ensure regulatory compliance (Santana, 2022). Similarly, in the transportation sector, small logistics firms can collaborate with community colleges to offer certification programs for commercial driving and supply chain management. The Community College of Philadelphia exemplifies this model by working with SMEs to upskill employees in logistics and transportation operations (Community College of Philadelphia, 2024).

The adoption of cost-effective training models, such as virtual and simulation-based programs, can also offer SMEs scalable solutions to upskill their workforce without significant infrastructure investments. In the healthcare sector, small clinics and rural hospitals can use simulation tools like Laerdal's SimMan to train nurses and medical staff in emergency response and telehealth operations, ensuring ongoing professional development at a reduced cost (Bliss *et al.*, 2022). Similarly, in the energy sector, small renewable energy firms can adopt simulation-based maintenance training for technologies such as solar microgrid systems. Organizations like the International Renewable Energy Agency (IRENA) promote affordable simulation-based training specifically designed for SMEs operating in renewable energy markets. To bridge technology and innovation gaps, SMEs can focus on workforce training that integrates emerging technologies. For example, in the water sector, small companies can train their workforce in IoT-enabled water distribution monitoring to improve efficiency and reduce leakages. LeakFinder, a small water management company based in Westbury, New York, successfully implemented such training in collaboration with technology providers. For example, they have collaborated with Echologics to implement advanced leak detection technologies and training. This partnership has enabled LeakFinder to enhance their capabilities in identifying and managing leaks more efficiently (Echologics, 2023). In the energy sector, small solar installation firms can train employees to operate advanced systems, such as microgrid management tools, with the support of institutions like the National Renewable Energy Laboratory (NREL), which offers hands-on workshops tailored to SMEs.

Finally, improved access to certification and regulatory training is another critical area for SMEs, as it enhances compliance with industry standards and builds sector credibility. In the healthcare sector, small diagnostic laboratories can train lab technicians to achieve ISO 15189 certification, ensuring adherence to international quality standards. Organizations like the American Society for Quality (ASQ) offer tailored certification pathways for SMEs (American Society for Quality, 2024). Likewise, in the transportation sector, small trucking companies can collaborate with state transportation agencies to train drivers on fleet safety certifications and environmental compliance, aligning their operations with sustainability-focused regulations like the Clean Air Act. Moreover, workforce training strategies that address emerging threats and risk management can strengthen SMEs' resilience against disruptions.

6. Policy-Level Implications for Workforce Training in SMEs

Given the critical role of SMEs in the energy, water, transportation and healthcare sectors, targeted policy interventions can enhance workforce training and preparedness. Governments play a pivotal role in ensuring that SMEs have access to the necessary resources, training programs and financial incentives to develop a skilled and resilient workforce. One key policy consideration is increased government funding for SME workforce training through direct subsidies, training grants and low-interest loans. As mentioned earlier, many SMEs struggle with the financial burden of continuous workforce development, particularly in high-tech sectors requiring specialized skills. Government-backed funding mechanisms, such as sector-specific training grants or workforce development tax credits, could incentivize SMEs to invest in employee training without compromising operational budgets. For example, in the energy sector, the U.S. Department of Energy (DOE) has provided funding for workforce training in renewable energy technologies, a model that could be expanded to other critical infrastructure sectors.

Also, currently, workforce training requirements vary widely across sectors and regions, leading to inconsistencies in skill levels and preparedness. Establishing baseline national training requirements—particularly for SMEs operating in safety-sensitive industries such as healthcare and transportation—could ensure a minimum competency level across the workforce. However, such standardization must be flexible enough to accommodate the unique needs and capacities of smaller enterprises. A tiered approach, where SMEs can adopt training modules relevant to their specific operations while meeting overarching national standards, may be an effective compromise. Tax incentives and grants could further promote industry-academic collaborations in workforce training, promoting partnerships between SMEs and educational institutions. By offering tax deductions or direct grants for SMEs that engage in training partnerships with universities, technical colleges and industry associations, governments can help bridge the skills gap while reducing financial barriers for small businesses. For instance, countries like Germany and Singapore have successfully implemented co-funded vocational training programs where businesses receive government support for employee upskilling. A similar approach could be tailored for SMEs in critical infrastructure sectors, ensuring they have access to cutting-edge workforce development resources. Additionally, governments could support public-private training initiatives that address emerging workforce challenges, such as the integration of digital

tools, automation and climate-resilient technologies. This could involve funding collaborative research initiatives between SMEs, universities and technology providers, as well as establishing innovation hubs that offer subsidized training in advanced industry practices.

By implementing these policy measures, governments can help SMEs build a future-ready workforce, enhance sectoral resilience and ensure that critical infrastructure sectors remain operationally efficient in the face of evolving challenges.

6. Contributions of the Research

This research makes several unique contributions. While previous studies primarily focus on large organizations, this study uniquely highlights the challenges and opportunities specific to SMEs. SMEs play a crucial role in maintaining critical infrastructure, yet they often lack access to advanced training resources (Dawson *et al.*, 2021). By addressing this gap, the study brings much-needed attention to the workforce training needs of SMEs, which are frequently overlooked in both research and policy discussions. A key advancement of this study is its systematic evaluation of workforce training strategies across multiple critical infrastructure sectors, including energy, water, transportation and healthcare. Unlike prior research that often examines training approaches in isolation, this study takes a cross-sectoral perspective, identifying common challenges and best practices that can be adapted to different sectors. Beyond identifying training gaps, this research goes a step further by offering tailored and actionable recommendations for SMEs. Many workforce training studies highlight deficiencies without providing feasible solutions, but this study proposes scalable, cost-effective training strategies that align with the resource constraints faced by smaller enterprises. This is further summarized in Section 4.4. This study also advances the field by shifting the focus from infrastructure resilience to workforce resilience. While much of the existing literature discusses the physical and technological aspects of protecting critical infrastructure, this research highlights the pivotal role of frontline employees in ensuring operational continuity during crises. By integrating insights from disciplines such as engineering, business management and crisis management, the study offers a holistic perspective on workforce training, ensuring that employees are equipped to handle evolving threats such as climate change impacts, cybersecurity breaches and cascading disruptions.

7. Conclusions

This review highlights the diverse workforce training strategies currently utilized within critical infrastructure sectors, emphasizing their relevance to improving employee skills, resilience and adaptability in the face of evolving challenges. Six strategies were identified in this review: (1) traditional and core skills training, (2) technology integration and innovation training, (3) emerging threats and risk management training, (4) certification and regulatory compliance training, (5) partnerships with educational institutions and (6) simulation-based and virtual training. Small and medium-sized enterprises (SMEs), which often face resource constraints, stand to benefit significantly from adopting these strategies. Through collaborations with universities, leveraging affordable simulation-based tools, or accessing government-sponsored training programs, SMEs can address workforce gaps while maintaining operational efficiency. Despite these opportunities, challenges persist, particularly in funding, awareness and accessibility, underscoring the need for tailored interventions and policy support. This study demonstrates the practical applicability of workforce training initiatives, providing actionable insights for SMEs to enhance their workforce preparedness. By adopting innovative training models and forming strategic partnerships, SMEs can not only meet regulatory demands but also build a skilled workforce capable of thriving in increasingly complex and interconnected environments. Future research could explore longitudinal impacts of training programs across different sectors and further investigate cost-effective solutions for SMEs in underserved regions, ensuring that critical infrastructure sectors remain resilient and secure.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors Biographies

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