



# The impact of interventions on health, safety and environment in the process industry

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## ABSTRACT

The process industry is recognized for its intricate nature and potential risks, necessitating the implementation of effective measures to ensure the well-being of individuals, promote safety, and protect the operational environment. This study aims to assess the impact of interventions on health, safety, and environmental (HSE) outcomes within the process industry. Various intervention strategies, such as engineering controls, administrative controls, personal protective equipment (PPE), and behavioral interventions, have been adopted to address challenges associated with fire, explosions, product leaks, occupational health hazards, and mechanical failures. These interventions are designed to mitigate risks resulting in injuries, illnesses, environmental incidents, and property damage. Research indicates that interventions have positively affected HSE outcomes in the short term, including improved worker safety, reduced hazards, and enhanced safety behavior. Furthermore, long-term evaluations have demonstrated sustained improvements and risk reduction. Combining multiple intervention types, such as engineering controls, administrative controls, PPE, and behavioral interventions, has proven to be the most effective approach, synergistically enhancing HSE outcomes. The findings emphasize the importance of thoughtfully considering and implementing interventions in the process industry to safeguard individuals' well-being, protect the operational environment, facilities and enhance overall safety performance.

## 1. Introduction

Since its establishment in the 18th century, industrialization has experienced significant changes and advancements. The subsequent major transformation occurred in the 19th century with the introduction of electricity, enabling widespread power distribution from centralized sources. This came after introducing machinery powered by local steam generation, which freed production from the constraints of human manual effort (Industrial Revolution 1.0). Electricity allowed machinery to run faster and with less weight (Industry 2.0). Powered assembly lines were introduced in the 20th century, and as electronics advanced, production became more and more automated (Industry 3.0) and performance oriented. Automation opened the potential for industrial process optimization and productivity enhancement by constructing more adaptable, ergonomic, and safer equipment [1].

The fourth industrial revolution is known as "Industry 4.0". The process industry includes industries that generate, manufacture,

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and refine products utilizing physical, chemical, or biological processes. Chemicals, petrochemicals, pharmaceuticals, and food and beverage processing are examples of processes that comprise this industry. The process industry has a long history dating to the early days of chemistry and manufacturing before the Industrial Revolution. According to the report [2], the analysis estimates that the worldwide process industry market size was valued at USD 4.88 trillion in 2019 and would increase at a CAGR of 4.0 % from 2020 to 2027. This shows that the process sector is still important today and is expanding. However, the industry is complex and hazardous, posing significant risks to the health and safety of workers and the environment. Thus, this industry is characterized by continuous or batch production methods, intricate supply chains, and a strong emphasis on complying with rigorous regulations. Furthermore, process industries frequently work with hazardous chemicals, substances, and processes, substantially raising the risk of operational catastrophe in their activities, such as operations under temperatures and pressures that are extremely high or low, respectively, which might pose a serious risk to the facilities and operational environment [3–6].

Therefore, implementing health, safety, and environmental (HSE) management systems within the process industry is necessary by considering several high-profile incidents that took place in the process industry, such as the Bhopal (1984) incident in India, 42 tons of methyl isocyanate were unintentionally released [7]. The incident had disastrous consequences. The deadliest process industrial accident in human history, according to reports at the time [8]. However, the exposed population to the gas leak was above 500,000. Various estimates place the total number of short-term fatalities at between 3000 and 10,000, although they also note that the health of roughly 500,000 people experienced long-term, permanent effects [9]. The Chernobyl accident of (1986) occurred because of a defective reactor design that was run by employees who were not properly qualified. Radioactive materials were deposited in numerous regions of Europe due to the steam explosion and fires, which released at least 5 % of the radioactive reactor core into the environment [10,11].

Piper Alpha (1988), originally built in 1976 for oil exploration, Piper Alpha was a production platform in the North Sea. In 1980, it underwent further modifications to enable increased gas production, and it was also linked to the Orkney Islands' Flotta oil terminal. On July 6, 1988, an immense accident destroys the facility, killing 167 persons and injuring many more [12]. Deep-water Horizon (2010), the drilling rig, was destroyed by an explosion on April 20, 2010, at the final phase of the exploratory Macondo well drilling in the Gulf of Mexico. 11 workers were killed instantly because of the disaster, and over four million barrels of oil were released in the Gulf, leading to the greatest accidental spill of oil in the US's history [13].

Additionally, on December 11th, 2005, an overfilled fuel (gasoline) storage tank at the Buncefield oil storage facility in the United Kingdom. However, this was caused by the breakdown of an automatic tank measuring system. For example, the alarm could not send signals to control systems [6,14]. Furthermore, the incidents that occurred in the process industry have highlighted the importance of HSE and prompted a renewed focus on the implementation of HSE management systems. However, the International Council of Chemical Associations (ICCA) has created a set of HSE management principles for the worldwide chemical industry, including the process industry. And a strong emphasis on integrating HSE management into all process industry components, from design and construction through operation and maintenance. The Guidelines also advocate risk analysis, emergency planning, and continual HSE management system monitoring and review.

Furthermore, regulatory bodies such as the International Organization for Standardization (ISO), which has developed several types of standards for HSE management systems, the European Union's Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), the United States Occupational Safety and Health Administration (OSHA), and others have come to acknowledge the importance of HSE in the process industry. Additionally, among the most essential interventions for improving HSE performance in the process industry is the implementation of a comprehensive HSE management system (HSEMS). Furthermore, adopting a thorough HSE management system (HSEMS) is one of the most critical interventions for enhancing HSE performance in the process industry.

Incorporating health, safety, and environmental concerns into every facet of the process industry—from design and building to operation and maintenance—is the goal of the HSEMS framework. HSEMS aims to develop a proactive safety approach that foresees potential hazards and mitigates them to stop incidents before they happen. Also, in the study of (Vaňková et al., 2021), the incidence and severity of accidents were lower in companies with the highest levels of HSEMS implementation than in those with lower levels. Safety audits and inspections are crucial interventions for enhancing HSE performance in the process industry. These interventions entail thorough examinations of the workplace to spot risks and gauge the efficiency of current safety measures. It has been demonstrated that safety audits and inspections are useful in pinpointing problem areas and averting incidents [15].

Another crucial intervention in raising HSE performance in the process industry is the introduction of safety training programs. These programs should arm employees with the information and abilities they need to recognize dangers, take precautions to reduce them, wear safety gear as directed, and react effectively in an emergency [16]. Additionally, enhancing HSE performance in the process industry depends on developing and implementing safety culture initiatives. Safety culture interventions aim to alter an organization's attitudes, convictions, and safety-related actions. These interventions include recognizing and rewarding workers who act safely, improving safety communication and feedback systems, and encouraging a culture of shared accountability for safety inside the company [17].

The present effort aims to investigate the Impact of Interventions on health, safety, and the Environment in the Process Industry. The research objectives are as follows:

- i. To identify and categorize different types of interventions utilized in the process industry to enhance HSE.
- ii. To evaluate the effectiveness and efficiency of interventions in improving HSE performance indicators, such as accident reduction, safety culture, and environmental sustainability.
- iii. To investigate the factors influencing the success or failure of interventions in the process industry.

The rest of this paper is organized as follows: Section 2 Overviews theories and concepts related to HSE interventions; Section 3 Integration and Sustainability of HSE Interventions. Finally, the conclusions and recommendations of this research are presented in Section 5.

## 2. Overview of theories and concepts related to HSE interventions

The theoretical underpinnings of the impact of interventions on Health, Safety, and Environmental (HSE) performance can be explored through various frameworks and models. A framework commonly used in HSE management is the Plan-Do-Check-Act (PDCA) cycle. This framework emphasizes the importance of continuous improvement through a cyclical process of planning, implementing, monitoring, and reviewing interventions. The PDCA cycle has been widely employed in various interventions to improve HSE performance. For instance Ref. [18], conducted a study that applied the PDCA cycle to enhance HSE performance in construction projects. The study demonstrates the practical application and effectiveness of the PDCA framework in driving continuous improvement and achieving better HSE outcomes.

In addition, safety audits and inspections serve as critical interventions for enhancing HSE performance in the process industry. These interventions involve systematic evaluations of the workplace to identify potential hazards and assess the effectiveness of existing safety measures. Research conducted by Ref. [19] in Pakistan highlighted the effectiveness of regular safety audits in the chemical industry, showing a decrease in the frequency and severity of workplace incidents. Another study conducted by Kim et al. (2018) in South Korea demonstrated that implementing safety training programs for workers in the chemical industry resulted in improved safety performance and reduced the number of incidents. In summary, these theoretical frameworks and models offer a foundation for comprehending how interventions can impact HSE performance. By utilizing these models and frameworks, professionals can design HSE interventions that effectively target the intricate and interrelated factors influencing HSE outcomes. The application of these models and frameworks enhances the development of evidence-based interventions that contribute to improved HSE performance. Lastly, the theoretical underpinnings of the impact of interventions on Health, Safety, and Environment (HSE) performance in the process sector can be studied using numerous frameworks and theories. Here are several significant theoretical viewpoints that investigate the relationship between interventions and HSE performance:

### 2.1. Systems theory

Systems theory offers a valuable conceptual framework for comprehending the effects of interventions on Health, Safety, and Environment (HSE) performance within the process industry. By applying Systems Theory principles, companies can adopt a comprehensive approach to managing HSE interventions, leading to enhanced overall performance [20]. The following analysis delves into the practical application of Systems Theory in assessing the influence of interventions on HSE performance within the process industry. The following make up the systems theory:

- The interconnectedness of components: Systems Theory highlights the mutual reliance of components within a system. In the context of HSE interventions in the process industry, these are not standalone activities but interconnected with multiple system components. Such interventions include process enhancements, equipment modifications, training initiatives, and communication system upgrades. Recognizing the interrelationships among these components is crucial in evaluating the potential effects of alterations on HSE performance [21,22].
- Feedback loops: Within Systems Theory, feedback loops play a significant role and offer a valuable tool for evaluating the effects of interventions. In the process industry, interventions can generate positive and negative feedback on HSE performance. Positive feedback occurs when an intervention enhances a particular aspect of HSE performance, thereby triggering a cascade of favorable outcomes [23]. Implementing a fresh safety training program, as an illustration, can heighten workers' awareness, resulting in a decrease in incidents. Conversely, undesirable feedback occurs when an intervention unintentionally yields unfavorable outcomes. For instance, while installing new equipment may enhance operational efficiency, it might inadvertently raise the risk of exposure to hazardous substances. By comprehending and monitoring these feedback loops, unintended consequences can be identified, and interventions can be optimized to attain the desired HSE outcomes [24].
- Emergent characteristics: Systems Theory recognizes emergent qualities that arise from the interactions among components within a system. In the context of the process industry, interventions can give rise to emergent effects on HSE that cannot be foreseen by solely examining individual interventions in isolation [23,25]. For instance, integrating interventions like process modifications, training initiatives, and cultivating a stronger safety culture could substantially decrease incidents and establish a pervasive culture of safety throughout the organization. By comprehending the emergent characteristics of these interventions, organizations can unveil synergistic effects and formulate comprehensive HSE strategies.
- Following Systems Theory, analyzing system boundaries and the impact of external factors on HSE performance is crucial. External factors, such as legal regulations, industry standards, and stakeholder expectations, should be considered when implementing HSE interventions in the process industry [26]. Additionally, comprehending the potential effects of interventions on neighboring systems or subsystems necessitates an examination of the system's boundaries. For instance, a measure to improve worker safety may inadvertently amplify environmental risks. By considering system boundaries and external factors, organizations can mitigate potential adverse consequences and optimize interventions to enhance overall HSE performance [27].
- **Systems Thinking:** The application of Systems Theory promotes the cultivation of systems thinking, which entails viewing HSE interventions as integral components of a broader system and acknowledging their interconnectedness. Rather than concentrating

solely on individual interventions, systems thinking explores the interactions and mutual influence among interventions [25]. For instance, a modification in operational processes may necessitate corresponding adjustments in training programs and equipment maintenance practices. Organizations can employ systems thinking to identify possible conflicts, bottlenecks, and unforeseen consequences of individual interventions [28]. In the study conducted by Ref. [29] in the Iranian oil and gas industry, the Systems Thinking model was utilized to examine the obstacles and facilitators associated with implementing HSE interventions. Moreover, the Human Factors framework emphasizes the significance of individual, group, and organizational factors in influencing HSE performance. This approach facilitates a comprehensive evaluation of the impact of interventions on HSE performance and supports the development of integrated and synergistic strategies.

### 2.2. Human factors theory

Places emphasis on the significance of human behavior, cognition, and performance in shaping HSE (Health, Safety, and Environment) outcomes. It acknowledges that various individual and group factors, including skills, knowledge, attitudes, and decision-making processes, are crucial in determining safety performance. Interventions derived from human factors theory are designed to improve human capabilities, mitigate the likelihood of errors, and foster safer behaviors [24,30]. [31] Conducted a study focusing on developing and implementing a human factors toolkit to enhance HSE performance in the UK offshore oil and gas industry.

This study demonstrates the practical application and effectiveness of the Human Factors approach in improving HSE outcomes. A research conducted by Ref. [32] in Iran demonstrated a significant positive correlation between implementing Health, Safety, and Environment Management Systems (HSEMS) and safety performance within the petrochemical industry. These interventions aim to improve HSE (Health, Safety, and Environment) performance by fostering a culture of learning and continuous improvement within the organization [33]. However, when analyzing the influence of interventions on HSE performance from a human factors standpoint, the following observations can be made:

- Designing interventions with consideration for Human Factors Theory involves optimizing the design of work systems, processes, and equipment to align with human capabilities and limitations. These interventions prioritize ergonomic principles, workload management, cognitive abilities, and the interaction between humans and machines. By incorporating these factors, interventions can enhance safety, minimize errors, and improve HSE (Health, Safety, and Environment) performance [34].
- Error prevention and resilience interventions informed by Human Factors Theory aim to identify and tackle the root causes contributing to human errors and system vulnerabilities. These interventions involve implementing measures to prevent errors, such as effective processes, checklists, and feedback systems. By implementing these interventions, organizations can enhance their resilience and minimize the likelihood and impact of errors on HSE (Health, Safety, and Environment) performance [35].

### 2.3. Organizational culture theory

Places emphasis on the collective values, beliefs, and norms that exist within an organization and how they influence the actions and choices of employees. When it comes to interventions aimed at improving HSE performance, it is crucial to cultivate a safety culture that recognizes and prioritizes safety, promotes the reporting of hazards and incidents, and fosters a commitment to ongoing

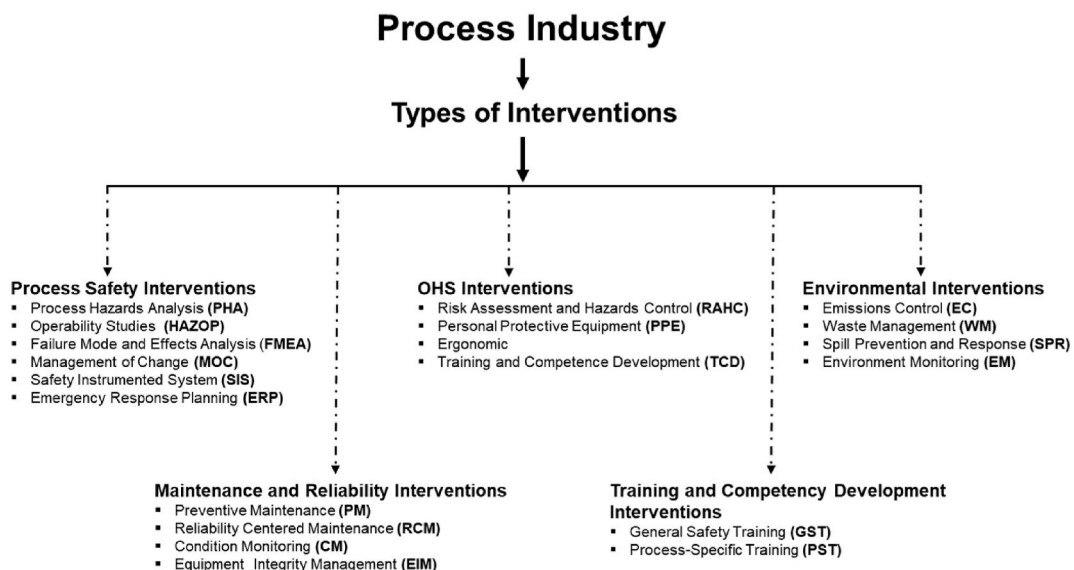


Fig. 1. Types of interventions in the process industry.

enhancement. This can also be achieved by encouraging open communication, promoting shared values regarding safety, and providing supportive leadership. These interventions aim to cultivate safe behaviors among employees and improve overall HSE performance [36,37].

#### 2.4. Types of interventions

In the process industry, different measures are taken to guarantee the well-being of workers, protect their safety, and ensure environmental conservation. These measures are specifically developed to tackle the industry's operational risks and potential hazards. Below are several typical types of measures implemented in the process industry. See Fig. 1. Types of Interventions in the Process Industry.

- **Process Safety Interventions:** Process safety interventions seek to minimize and mitigate the hazards associated with hazardous processes and equipment. These interventions incorporate with so many measures, such as Process Hazard Analysis (PHA): Conduct systematic evaluations, such as Hazard and Operability Studies (HAZOP) or Failure Mode and Effects Analysis (FMEA), to identify potential hazards and develop risk mitigation strategies. Implementing procedures to assess and manage the impact of changes to processes, equipment, or procedures on safety is performed by Management of Change (MOC) [38]. Furthermore, installing and maintaining automated safety systems, such as emergency shutdown systems and safety interlocks, to prevent or mitigate process incidents is achieved through Safety Instrumented Systems (SIS) [5,39]. Developing and practicing emergency response plans to ensure an effective response to process-related incidents, including evacuation, containment, and mitigation strategies in the process operations through Emergency Response Planning (ERP) [40].
- **Occupational Health and Safety (OHS) Interventions:** OHS interventions focus on protecting workers' health and safety in the workplace. Identifying possible risk factors at work, utilizing evaluations such as Job Safety Analysis (JSA) or Safety Data Sheets (SDS) is the intervention process. Following the identification of hazards, appropriate control measures are implemented to minimize risks, known as risk assessment and hazard control (RAHC) [41]. Furthermore, against specific industrial hazards, workers are provided with appropriate personal protective equipment, such as protective clothes, goggles, gloves, or respirators. Likewise, evaluating and modifying working tools and equipment will reduce ergonomics risks, such as musculoskeletal injuries among workers.
- **Environmental Interventions:** Environmental interventions in the process sector aim to reduce the industry's environmental impact. However, these interventions involve implementing actions to reduce air pollutants, such as installing pollution control devices or optimizing combustion processes which are known as emissions control (EC) [42]. Furthermore, creating strategies for processing, treating, recycling, or disposing of waste materials created during the production process is called waste management (WM) [43]. Spill prevention and response are implemented to measures, containment systems, and response methods to reduce the environmental effect of unintentional spills. Lastly, monitoring air quality, water discharges, and other environmental indicators regularly to maintain compliance with rules and find possibilities for improvement through environmental monitoring (EM).
- **Maintenance and reliability interventions:** Strive to guarantee that process equipment operates reliably and safely. Implementing routine inspections, lubrication, calibration, and equipment maintenance to reduce the risk of equipment failure is known as preventive maintenance (PM) [44]. Using systematic analysis to identify important equipment, failure modes, and appropriate maintenance procedures to improve equipment reliability is regarded as reliability-centred maintenance (RCM) [45], using techniques such as vibration analysis, thermography, or oil analysis to monitor the health of equipment and anticipate probable breakdowns in advance is conducted through the process known as condition monitoring (CM) [46]. Lastly, developing methods and techniques for evaluating and maintaining the integrity of important equipment such as pressure vessels or storage tanks is known as equipment integrity management (EIM).
- **Training and Competency Development Interventions:** Training interventions ensure that workers and people have the information and skills required to execute their jobs safely. It provides basic instruction on issues like danger awareness, emergency response, and safe work procedures, known as general safety training (GST). Lastly, special training can be provided for the worker in order to understand specific operations. In that case, the training is known as process-specific training (PST) [47,48].

#### 2.5. Interventions and It's applications

One of the most dangerous sectors in the world is the process industry. Risks in the industry include working with hazardous chemicals, high-energy processes, and heavy machinery, among others. HSE (Health, Safety, and Environment) interventions are crucial in the process industry for preventing accidents and injuries and protecting workers and the environment from potential hazards by implementing workplace operational strategies and practices. Also, other aspects of these incidents include loss of time and productivity, delay in delivery of goods and services, and exposure to complaints and low production levels.

Nevertheless, most of the worries above can be alleviated by instituting effective processes, monitoring and evaluation systems, and frequent assessments. Health, safety, and environmental (HSE) issues have developed into an inherent element of all operations and organization in the twenty-first century. A healthy and safe climate encourages people to live healthier lifestyles, and the concept of sustainable development has arisen to address contemporary social, economic, and environmental concerns [49]. However, HSE's overarching goal is to provide a structured strategy based on current standards to ensure that potential and actual risks to safety, health, the environment, and social obligations are appropriately recognized and controlled. In order to attain a reasonable and thorough understanding of these three concepts health, safety, and environment; the industry has developed the HSE management

system, which unifies these three domains.

In other words, the HSE is a management system to help organizations and enterprises address environmental challenges in their operation while also addressing their inadequacies in health and safety. To identify workplace dangers, reduce the frequency of accidents or incidents, and prevent exposure to hazardous circumstances and chemicals, organized processes must be established from a safety standpoint. Additionally, it offers instruction for staff members on how to use safety equipment, respond to emergencies, and prevent incidents [50]. From a health standpoint, the process industry should use safety processes of the highest caliber and environmentally friendly, as well as methodical procedures and actions that lessen the possibility of operator and employee injuries. From an environmental standpoint, this means creating a systematic strategy for environmental compliance, including risk management and eliminating or reducing harmful adverse substances.

Another research by Ref. [51] established a framework to classify organizational interventions that improve safety, with several treatments falling under each broad category. For instance, the main “Monitoring, Feedback and Learning Systems” category included supervision, task checking and monitoring, incident analysis, inspection, and review and feedback. Using the same framework, the “Safety Management Systems” category included a safety committee, specialist advisory service, safety officer, and risk assessment. [52], In their review, they noted several of the same interventions, good housekeeping, the quantity and length of training, carrying out safety audits, and delegating safety-related tasks. Nevertheless, accidents and injuries still happen despite the wide range of safety measures that can be used to ensure safe working conditions and the substantial information available for putting those measures into practice. However, this current research has tried to figure out some HSE elements that would help intervene in accidents, risk, workers’ health, and operational environment, which have yet to be explored in the study literature. See Fig. 2. HSE Intervention in the process industry.

- Hazard identification and risk assessment are crucial in the process industry. The process involves identifying potential dangers and evaluating their associated risks to prevent workplace accidents and injuries. Employing techniques such as job safety analysis, hazard and operability studies, and failure modes and effects analysis is vital for identifying and controlling risks. Risk assessment also aids in creating effective interventions for health, safety, and environment (HSE) to minimize or eliminate workplace risks [53].
- Behavioral safety constitutes a crucial element within HSE interventions in the process industry. It centres on modifying behavior patterns to enhance safety outcomes. This approach entails the identification of hazardous behaviors and the implementation of appropriate interventions to promote safe practices. Employing methods such as safety observations, feedback mechanisms, safety training, and introducing incentives and recognition programs can effectively encourage the adoption of positive safety behaviors [54].
- Safety culture holds significant importance in HSE interventions within the process industry. A favorable safety culture instils safety as a fundamental value in the workplace and fosters a proactive approach to safety. It encompasses shared values, attitudes, and beliefs concerning safety within an organization. By promoting safety as an intrinsic aspect of the job, a positive safety culture plays a pivotal role in preventing workplace accidents and injuries [55].
- The hierarchy of controls holds significant relevance in HSE interventions within the process industry. It entails implementing various control measures to minimize or eliminate workplace hazards. The hierarchy encompasses five types of controls:



Fig. 2. HSE Intervention in the process industry.

elimination, substitution, engineering, administrative, and personal protective equipment. By following the hierarchy of controls, risks associated with processes, equipment, and chemicals in the process industry can be effectively reduced [56].

- In summary, HSE interventions play a vital role in preventing accidents, injuries, and environmental harm within the process industry. Key concepts and theories such as hazard identification and risk assessment, behavioral safety, safety culture, and the hierarchy of controls are fundamental in HSE interventions within this industry. While implementing HSE interventions in the process industry can present challenges, involving workers in safety initiatives, offering sufficient training, and fostering a positive safety culture are effective strategies for overcoming these obstacles. By embracing these approaches, organizations can enhance safety outcomes and ensure a secure working environment.

## 2.6. Factors that influence HSE interventions

Interventions have a significant impact on Health, Safety, and Environment (HSE) outcomes within the process industry. To design and implement effective HSE initiatives, it is crucial to comprehend the essential factors and mechanisms that influence the effectiveness of these interventions. Additionally, to identify the factors and mechanisms that contribute to the impact of interventions on HSE performance in the process industry. Below are some factors and mechanisms through which interventions influence HSE outcomes with relevance. See Fig. 3. Factors that influence HSE interventions in the process industry.

- HSE management systems (HSEMS) are extensive frameworks designed to integrate health, safety, and environmental considerations throughout the entire organizational system, including design, construction, operation, and maintenance. The primary objective of HSEMS is to establish a proactive safety approach that anticipates and addresses potential risks, thereby preventing incidents. HSEMS interventions involve implementing codes, standards, and guidelines about safety management systems [57]. However, Thorough and visible HSMS programs have been linked to reduced injuries within many high-hazard industries, e.g., Refs. [58,59]. It also involves key aspects such as management commitment and leadership, active involvement of employees in the workplace, adopting a risk-based approach to management, fostering a safety-oriented culture, and implementing a continuous improvement process to manage risks at an acceptable level. Additionally, it emphasizes the importance of following a systematic Plan-Do-Study/Check-Act process [60,61].
- Training and Educational programs are designed to provide workers with the necessary knowledge and skills to prevent accidents and incidents associated with health and safety issues. These types of courses could include seminars in the classroom, job-based instruction, or simulation activities. However, imparting this knowledge will enhance the skills of workers, and these interventions significantly contribute to improving safety performance. Additionally, education can help workers understand the importance of following safety protocols and the consequences of not doing so. Training and Education can also help workers understand the importance of reporting safety issues or concerns; [62].
- Technological and Process Design: encompass the utilization of specially designed tools, equipment, and machines with a focus on safety. This encompasses safety equipment, control systems, and automated protective devices, all of which aim to minimize the likelihood of accidents and incidents within process areas [63]. In addition, the design of the process has the potential to reduce the



Fig. 3. Factors that influence HSE interventions in the process industry.

likelihood of events and accidents by making sure the process is built in such a way that mistakes made by humans are minimized. This can involve creating procedures that are simple to comprehend and implement, as well as creating essentially safe processes [64,65].

- Risk assessment plays a critical role in shaping health, safety, and environmental (HSE) outcomes within the process industry. It involves the systematic identification of potential hazards and the evaluation of their likelihood and severity of risks. By conducting thorough risk assessments, organizations can identify areas within the process that require improvement or modification to minimize the potential for accidents and incidents. The findings from risk assessments serve as a basis for implementing preventive measures and enhancing overall safety performance in the process industry [66].
- Auditing and Monitoring: In the process industry, auditing and monitoring are essential mechanisms that significantly impact health, safety, and environmental (HSE) outcomes. These processes play a crucial role in identifying any possible safety issues or concerns that may have been overlooked during risk assessment. Moreover, auditing and monitoring activities are instrumental in verifying adherence to safety protocols and ensuring proper implementation of any process changes. By conducting effective audits and monitoring procedures, organizations can proactively address potential safety risks and maintain compliance with established safety standards [67].
- Emergency Response plays a crucial role in maintaining the safety and effectiveness of the process operations. Organizations can ensure their operations' safe and efficient functioning by implementing an entire response to an emergency strategy. Furthermore, having a clearly defined plan in an organization would help tackle any possible emergency situations in the operational environment.

### 2.7. Impact of interventions on HSE performance

Implementing a comprehensive HSE management system (HSEMS) is a significant intervention in enhancing HSE performance within the process industry. HSEMS is an approach that incorporates health, safety, and environmental considerations into every phase throughout the industrial process, encompassing planning, development, operations, and management. The major goal of HSEMS is to make a preventative commitment to safety by recognizing and decreasing possible dangers to stop accidents before happening. By incorporating HSE considerations throughout the process, organizations can effectively manage risks and promote a safety culture. According to research findings, organizations that adopt Health, Safety, and Environmental Management Systems (HSEMS) have demonstrated enhanced safety performance and a decrease in the frequency and severity of incidents. For instance, a study conducted by Ref. [68] in the Czech Republic revealed that companies that had extensively implemented HSEMS experienced fewer and less severe accidents than those with lower levels of HSEMS implementation.

Another significant intervention in enhancing HSE performance within the process industry is the utilization of safety audits and inspections. These interventions encompass structured evaluations of the workplace, aiming to identify hazards and evaluate the adequacy of existing safety measures. The effectiveness of safety audits and inspections has been well-documented in identifying areas for improvement and preventing incidents. Furthermore, implementing safety training programs is crucial in improving HSE performance within the process industry. These programs equip workers with the necessary knowledge and skills to identify and mitigate risks, correctly utilize protective equipment, and respond appropriately during emergencies. Ensuring comprehensive safety training programs are essential for promoting a safe work environment and enhancing overall HSE outcomes [69].

Furthermore, the establishment and execution of safety culture interventions play a vital role in enhancing HSE performance within the process industry. These interventions target the transformation of attitudes, beliefs, and behaviors concerning safety within an organization. Examples of safety culture interventions include offering safety recognition and incentives to workers who exhibit safe practices, strengthening safety communication and feedback channels, and nurturing a collective sense of responsibility for safety within the organization. Implementing these interventions is crucial for fostering a positive safety culture and improving overall HSE outcomes in the process industry [70].

Additionally, Safety audits and inspections are crucial interventions for enhancing health, safety, and environmental (HSE) performance in the process industry. They involve systematic workplace evaluations to identify potential hazards and evaluate the adequacy and effectiveness of existing safety measures. Safety audits and inspections have demonstrated effectiveness in identifying areas requiring improvement and preventing incidents in the process industry. By conducting regular audits and inspections, organizations can proactively identify safety gaps, implement corrective actions, and ensure compliance with safety regulations and standards. These interventions contribute to maintaining a safe work environment, reducing risks, and continuously improving HSE performance [71].

In summary, Interventions targeted at enhancing HSE performance are crucial in mitigating the risks inherent in the process industry. Implementing a comprehensive HSE management system, conducting safety audits and inspections, providing safety training programs, and incorporating safety culture interventions are all valuable approaches for improving safety performance within the process industry. These interventions collectively contribute to a safer working environment and help to reduce the potential hazards associated with the industry.

### 2.8. Impact of PPE on HSE outcomes

Personal Protective Equipment (PPE), as outlined by the UK Health and Safety Executive Work Regulations (1992), is designed to offer protection to the wearer from hazards present in work environments [72]. It encompasses various facets, each serving distinct purposes [73]. These include ensuring safety for respiratory protection, hearing, shielding the skin, safeguarding the eyes, and



providing vital coverage through clothing to mitigate impact. Additionally, safety measures involve the use of impact-resistant helmets, rescue belts, and lifelines, crucial for life-saving purposes [74]. Personal protective equipment comes with inherent limitations and cannot eliminate all hazards [75]. Therefore, the selection of equipment should align with specific needs based on the conditions of use. Workers must undergo training and education before utilizing any safety equipment [76].

PPE is crucial in preventing worker exposure to hazards, as highlighted by the National Institute for Occupational Health and Safety [77]. [78] recommends the use of PPE when engineering and administrative controls are impractical or insufficient to reduce risks to acceptable levels. Utilizing PPE is a vital aspect of preserving workers' lives; according to Ref. [79], it is a more practical and straightforward method for workers to prevent construction accidents compared to other controls. The significance of using PPE is underscored in a recent study by Ref. [80], indicating that wearing appropriate PPE can prevent over 90 % of construction hazards at various worksites.

In summary, the use of PPE is integral to maintaining a safe workplace in compliance with health and safety standards. Adherence to instructions and policies, coupled with proper training and supervision of staff, enhances HSE outcomes. A safety management system within the industry encompasses the health and safety of workers, following company rules and regulations. In the event of an accident, individual prevention and safety planning are crucial components. PPE comprises products designed to safeguard users from various workplace hazards, reducing the risk of adverse effects under different conditions.

## 2.9. Evaluation of effectiveness and efficiency of HSE interventions

In the process industry, evaluating the effectiveness and efficiency of different intervention types can be crucial to improve safety, reduce costs, and increase productivity. Some examples of intervention types that can be evaluated include:

- Process enhancements seek to increase efficiency and safety by modifying equipment, procedures, or organizational structure. Critical performance indicators such as production rates, cycle times, and safety issues must be monitored to evaluate their success.
- Performance Metrics, choose appropriate HSE performance measures that correspond to the goals of each intervention. Indicators such as incident rates (e.g., LTIFR, TRIR), absenteeism rates, compliance levels, energy consumption, trash generation, or stakeholder satisfaction scores could be included. Use these indicators to track the effectiveness of interventions over time.
- Automation and technology, these interventions entail the use of new technologies to increase efficiency and safety, such as sensors, robotics, or artificial intelligence. Tracking measures such as productivity, uptime, and maintenance costs can be used to assess their efficacy.
- Cost-Benefit Analysis is by comparing the costs and benefits of various interventions kinds. It is critical to examine both physical costs, such as training fees and equipment upgrades, and intangible benefits, such as improved safety culture and reputation. This analysis aids in determining the efficacy and cost-effectiveness of the remedies being considered.

## 2.10. Short-term and long-term effects of interventions on HSE

Implementing plans to improve health, safety, and environment (HSE) are grouped into two types, such as short and long-term implications. The nature of the intervention, the environment in which it is conducted, and organizational operations can impact the outcomes of the interventions.

### Short-term Effects:

- By enhancing safety measures, interventions such as improved training protocols, stricter safety guidelines, and enhanced equipment maintenance. These measures can help prevent accidents, reduce injuries, and promote a safer working environment in the short term.
- By increasing awareness, interventions often involve raising awareness among workers about HSE practices and potential risks. This heightened awareness can lead to a temporary increase in safety consciousness and a more proactive approach to addressing hazards.
- By improving emergency response, Interventions may focus on strengthening emergency response protocols and preparedness. This can result in quicker and more effective responses to accidents or incidents, minimizing their immediate impact [81,82].

### Long-term effects:

- Through cultural shifts, interventions can help to build a safety culture in the process industry over time. This entails making safety practices and attitudes an integral part of the organizational culture. A strong safety culture encourages consistent adherence to safety rules and promotes a proactive risk identification and mitigation approach.
- Through continued enhancement, interventions such as regular safety audits, incident investigations, and feedback loops may support the adoption of continuous improvement procedures. These practices have the potential to lead to the discovery of systemic issues and the execution of corrective actions, resulting in long-term improvements in HSE results.
- Through technological advancements, interventions frequently stimulate the introduction of new technology and ideas targeted at improving HSE outcomes. Over time, these developments may result in the development of more efficient and safer processes, less environmental impact, and greater overall sustainability [83,84].

- In summary, it's important to note that the specific short-term and long-term effects of interventions on HSE outcomes in the process industry can vary depending on the nature of the interventions, the industry's unique characteristics, and the level of commitment from stakeholders.

### 2.11. Factors that contribute to HSE intervention success

Examines the factors influencing the success of health, safety, and environmental (HSE) interventions in the process industry. Identifying and analyzing these factors will offer valuable insight into the crucial elements contributing to HSE interventions' success. Understanding these factors can aid organizations in implementing interventions that generate favorable outcomes and enhance HSE performance within the process industry. However, the factors it is as follows, Process Safety Leadership and Process Safety Management Support, Employee Involvement and Engagement, Effective Communication, Adequate Training and Competence, Resource Availability and Infrastructure, Regulatory Compliance, Monitoring, Evaluation, and Continuous Improvement, Organizational Culture and Climate and Collaboration and Learning from Experience. Fig. 4. The nine primary components factors of HSE success in the process industry.

#### 2.11.1. Process Safety Leadership and Process Safety Management Support

In the process industry, the most effective system for measuring performance is the involvement of leadership and senior management teams in process safety management. Compliance with regulations alone is insufficient for ensuring process safety; organizations must continuously improve to maintain sustainability. Process safety management should be seen as a balance between engineering and management, as both aspects rely on human impact, which is influenced by leadership. Effective leadership requires a thorough understanding of potential risks, existing safeguards, and the use of performance monitoring data to make informed decisions. This explains the emphasis on leadership in the process safety industry, as leaders must actively engage in safety practices [85, 86].

Additionally, process safety leadership and management intervention in Health, Safety, and Environment (HSE) ensure that safety becomes ingrained in the organization's core values, day-to-day operations, and decision-making procedures. This intervention fosters a proactive safety culture, boosts employee engagement, and, as a result, establishes a safer work environment within the process industry, as well as reducing risk and hazards exposure, enhanced productivity, fewer operational accidents, fewer occupational diseases and work-related health problems, higher motivation to workers and lesser turnover [87].

#### 2.11.2. Employee Involvement and Engagement

The participation and commitment of employees in Health, Safety, and Environment (HSE) initiatives are essential for promoting a robust safety culture in the process industry. When employees are actively involved and engaged in HSE practices, organizations can greatly improve safety performance and minimize the likelihood of workplace accidents and incidents [88]. This section examines the significance of employee participation and commitment in HSE and effective intervention strategies in the process industry [88]. Worker involvement applies to workers' effective participation in procedures relating to health, safety, and the environment (HSE), as well as decision-making and initiatives targeted at enhancing safety. When employees participate in these operations, organizations can tap into their knowledge, skills, and viewpoints, allowing them to contribute to discovering hazards, risk assessment, and initiatives to improve safety. Employees possess a profound understanding of their tasks, enabling them to provide valuable insights into potential risks and ways to improve safety [89,90].

There are numerous advantages associated with involving employees in HSE. Primarily, it enhances employees' awareness of

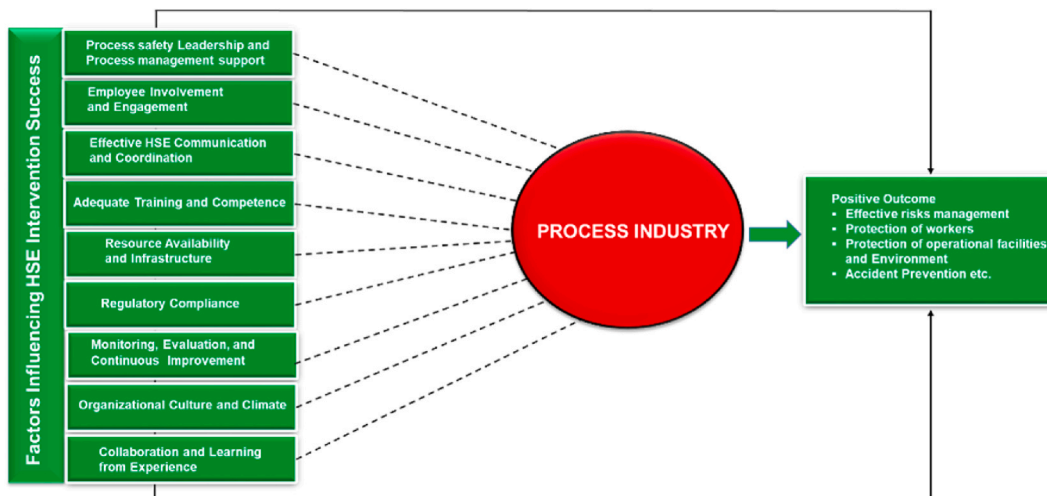


Fig. 4. The nine primary components factors of HSE success in the process industry.

hazards. Through active participation in HSE endeavours, employees become more mindful of potential dangers and risks inherent in their work processes. This heightened awareness enables them to proactively identify and report safety concerns, leading to timely interventions and preventive measures [91,92]. The active participation of employees in HSE initiatives not only increases hazard awareness but also contributes to the improvement of safety practices. Employees engaged in HSE activities are more likely to comply with safety protocols, follow safe work procedures, and actively participate in safety training. This active involvement transforms them into safety advocates who take personal responsibility for safety and actively promote a secure work environment [92,93].

#### 2.11.3. *Effective HSE communication and coordination*

The significance of communication in building a safety culture is generally acknowledged. Establishing a two-way communication channel between senior management and employees is essential for addressing employee requirements and giving them a sense of safety and job security [94,95]. This communication is essential for effectively implementing risk assessment in factories. When managers, supervisors, and employees communicate and coordinate with each other, it helps resolve safety issues and facilitates information sharing. For instance, reporting near-miss incidents encourages the implementation of more practical measures to prevent major accidents [95].

Also, communication aims to ensure that everyone understands their duties and responsibilities regarding workplace safety and health [96]. Confirmed that the more open communication focusing on issue-solving and learning, the more workers become involved in safety management and provide suggestions for future job improvements. Such worker participation implies a higher level of safety performance. Furthermore, it was noted that when a two-way communication technique is adopted, the coverage and impact of communication will be expanded, which could lead to behavioral transformation in personnel [97].

#### 2.11.4. *Adequate Training and Competence*

Workers who recognize the importance of enhancing their abilities tend to display increased engagement and dedication towards safety training and other types of training. This inclination enables them to enhance their performance and maintain a safer work environment. However, training is designed to raise knowledge of potential dangers and risks. Effective safety training is critical to any successful company and safety and health program. Training, in general, aids in the improvement of employees' behavioral skills, knowledge, and/or attitude. For instance Ref. [98], supported the notion that training contributes to developing employee competence in risk prevention abilities, talents, and aptitudes.

Similarly [97] emphasized that safety training is an effective method of safety management that allows for the prediction of workplace incidents. Employee competence is a critical aspect of ensuring safe production processes, and the success of training in achieving safety objectives is greatly influenced by the involvement of supervisors, managers, and safety and health committees that oversee production activities [99]. Researchers such as [100,101] have found that organizations with low accident rates often implement practical safety training, demonstrating the effectiveness of adequate HSE practices in the process industry.

#### 2.11.5. *Resource Availability and Infrastructure*

The availability of resources and infrastructure are critical in improving health, safety, and environmental (HSE) interventions in the process industry. Enough resources, including tangible and intangible components, are required to enforce health, safety, and environment (HSE) regulations and provide a safe working atmosphere. Furthermore, funds must be set aside to support expenditures in safety equipment, technology, training programs, and maintenance activities. The expenditures of procuring and maintaining personal protective equipment (PPE), safety monitoring systems, emergency response equipment, and other safety-related resources are included in this financial allocation. Proper financial backing enables firms to dedicate the resources needed to effectively handle HSE risks and hazards.

#### 2.11.6. *Regulatory compliance*

Regulatory compliance plays a significant role in HSE interventions within the process industry. Following appropriate guidelines, legislation, and standards is critical for guaranteeing worker safety, conserving the environment, and fostering community well-being. The following are important variables to consider:

- **Legislation:** HSE operations within the process industry are guided by a range of legal obligations. These regulations differ across jurisdictions but typically encompass occupational health and safety laws, environmental protection, and industry-specific standards. Adhering to these regulations is crucial to prevent accidents, mitigating risks, and effectively handling hazardous substances and procedures [102].
- **Industry Standards and Recommendations:** Alongside legal obligations, industry-specific standards and guidelines guide HSE initiatives. Reputable organizations or industry associations often develop these standards. For instance, the International Organization for Standardization (ISO) has created ISO 45001 as a framework for managing occupational health and safety. Adhering to these standards demonstrates a dedication to adopting best practices and assists in achieving regulatory compliance.
- **Government Oversight:** Regulatory bodies have a significant role in overseeing and enforcing HSE compliance within the process industry. These authorities can be government entities operating at different levels or specialized organizations responsible for occupational health and safety and environmental protection. They conduct inspections, audits, and evaluations to verify that companies adhere to regulations, maintain necessary documentation, and implement suitable corrective measures [103].

### 2.11.7. Monitoring, evaluation, and continuous improvement

Regularly tracking, assessing, and enhancing safety measures is essential in ensuring the effectiveness of Health, Safety, and Environment (HSE) interventions in the process industry. By monitoring and evaluating current safety measures and identifying areas for improvement, organizations can effectively mitigate potential risks. This enables the organization to continuously improve its safety measures and maintain a safe working environment. The following are important key factors to consider:

- **Monitoring** refers to gathering and examining data to evaluate the effectiveness of health, safety, and environment (HSE) interventions. It allows organizations to assess the impact of safety measures and identify any potential risks or instances of non-compliance. Through the regular monitoring and tracking of key performance indicators (KPIs), organizations can gauge their advancements and make well-informed decisions grounded in dependable data. This practice aids in preserving and enhancing safety measures, thereby ensuring a secure work environment [104].
- **Evaluation** examines the impact and outcomes of health, safety, and environment (HSE) actions. It goes beyond mere monitoring and aims to assess the effectiveness of implemented safety measures in achieving the desired safety goals. This evaluation process involves systematically analysing data, gathering stakeholder feedback, and comparing the results against predetermined objectives. Through evaluating HSE interventions, organizations can identify the strengths, weaknesses, and areas in need of improvement within their safety programs [105].
- **Continuous Improvement** is a strategy that aims to consistently enhance health, safety, and environment (HSE) interventions. It involves a cyclical process of reviewing, monitoring and assessing results, identifying gaps or deficiencies, and implementing corrective actions to address them. By fostering a culture of continuous improvement, organizations can ensure that their HSE practices evolve and adapt to new industry standards, technological advancements, and best practices [106].

### 2.11.8. Organizational culture and climate

The success of health, safety, and environmental (HSE) interventions is heavily influenced by corporate culture and climate in the process sector. Effective safety culture is required to create an environment where workers can freely raise concerns, and safety is woven throughout the organization's operations. The adoption of safety management systems (SMS), which provide a systematic approach to safety management by detecting hazards, evaluating risks, and applying preventative actions to prevent accidents, is one useful intervention in the process industry. Discovered that SMS implementation was connected to lower injury rates in the refining and petrochemical sectors.

Additionally, organizations can identify areas in need of improvement and take proactive measures to address potential safety risks. A study conducted by Ref. [107] indicated that safety performance metrics were positively linked to safety culture and employee safety behavior in the Iranian oil and gas industry. In summary, HSE interventions focusing on organizational culture and climate are crucial for promoting a safe and healthy work environment in the process industry. By implementing safety management systems, fostering safety leadership, providing effective safety training, and utilizing safety performance metrics, organizations can enhance their safety culture and mitigate the risks of accidents and injuries.

### 2.11.9. Collaboration and learning from experience

The process industry is commonly associated with risky operations. Therefore, the industry has developed strategies to control health, safety, and environmental (HSE) interventions. The utilization of collaborative approaches and knowledge sharing have been recognized as crucial elements in the implementation of effective HSE interventions. However, collaboration among companies is crucial in promoting the sharing of best practices in HSE interventions. By leveraging the experiences and outcomes of other organizations, companies can adopt effective strategies, tools, and technologies to enhance their safety performance [108]. Collaboration platforms, including industry associations, conferences, and working groups, offer avenues for exchanging knowledge regarding risk assessments, safety protocols, emergency response plans, and incident investigation methodologies. These platforms facilitate disseminating valuable information, enabling organizations to learn from each other's successes and failures and improve their overall HSE practices.

Near-miss incidents provide valuable opportunities for learning and improving health, safety, and environmental (HSE) interventions. Promoting the reporting and analysis of near-miss incidents encourages a proactive safety mindset. By fostering collaboration, organizations can share information about near-misses, identify recurring patterns, and implement preventive measures to prevent similar incidents from occurring in the future [109]. Collaboration platforms, such as shared incident databases or industry-specific forums, facilitate the exchange of near-miss data and foster collective learning. Furthermore, regulatory authorities play a substantial part in assuring compliance with health, safety, and environmental (HSE) norms. Collaboration between industry players and regulators is critical in the development and execution of effective policies. Companies that actively participate in conversations with regulators can provide their know-how, address industry-specific issues, and significantly contribute to creating realistic and successful HSE legislation [110]. Regular dialogues and workshops facilitate the exchange of knowledge, alignment of expectations, and identification of emerging risks.

Furthermore, studying important incidents provides invaluable information for the process sector. When process companies, regulatory authorities, and independent specialists work together during accident investigations, they can completely examine the basic causes, systemic problems, and areas for improvement [111]. The reports and conclusions of these investigations serve as critical learning resources, informing the development of preventive and corrective measures. Sharing the knowledge obtained from big accidents helps to improve health, safety, and environmental (HSE) measures across the industry.

### 3. Integration and Sustainability of HSE interventions

It is critical to recognize and underline the importance of establishing and maintaining interventions in the process operations. These interventions are essential for increasing safety, health, and Environmental sustainability. In addition, it is essential to implement plans with a focus on long-term advantages and sustained effectiveness to ensure the long-term sustainability of interventions. Considering the long-term benefits and ongoing efficacy of the implemented plans helps to avoid short-sighted solutions. Organizations can lay a solid basis for long-term sustainability by taking a thorough and forward-thinking strategy. This method ensures that the interventions continue to provide beneficial results throughout time. By prioritizing long-term benefits, the process industry can adapt and thrive amidst changing circumstances, fostering continuous improvement and long-lasting success [112,113]. Here are some important factors to consider while integrating and maintaining interventions in the process industry:

- It is important to recognize the value of performing a thorough Life Cycle Assessment (LCA) to assess the environmental repercussions associated with a product or process from its inception to its ultimate disposal. In assessing all phases, from the acquisition of raw materials through final disposal, it is possible to identify particular locations where interventions might be taken to improve sustainability [114].
- It is essential to identify that the goal of process integration is to improve the general productivity of a production system by reducing energy consumption, waste generation, and resource use. Analyzing the interconnections among different processes allows opportunities for recovering energy and resources to be identified.
- It is crucial to recognize the significance of adopting cleaner production practices, which entails minimizing waste generation, emissions, and the utilization of hazardous substances. The objective above can be achieved in various ways, including heat integration, mass integration, and water management measures. Identifying specific sites where interventions could be made to increase sustainability is possible by examining all steps, from raw material acquisition to final disposal.
- It is imperative to recognize the significance of adopting cleaner production practices, which entails minimizing waste generation, emissions, and the utilization of hazardous substances. This objective can be accomplished by implementing process modifications, upgrading technologies, and embracing cleaner alternatives. Furthermore, enhancing process control systems and performing routine maintenance can optimize resource efficiency and decrease the environmental footprint.
- Embracing the principles of a circular economy involves minimizing waste generation and maximizing the recovery and reuse of resources. By closing material loops and reducing the dependence on virgin resources, the process industry can enhance sustainability and resource efficiency.
- It is crucial to perceive sustainability interventions as an ongoing and evolving process that necessitates continuous improvement and innovation. Frequent monitoring, evaluation of data, and benchmarking are essential tools for identifying areas that require additional intervention and ensuring that sustainability targets are met.
- Adhering to environmental regulations and standards is crucial for sustainable operations. Integrating interventions that not only meet but exceed regulatory requirements can help mitigate risks, enhance the industry's reputation, and ensure long-term sustainability [115,116].
- In summary, it is important to recognize that integrating and sustaining interventions in the process industry requires a comprehensive approach that considers the entire value chain and encompasses economic, environmental, and social objectives. To ensure both environmental responsibility and commercial viability, the industry can optimize its processes, minimize waste generation, incorporate renewable energy sources, and embrace the principles of the circular economy. The industry can minimize its environmental impact by adopting these measures while remaining economically sustainable.

#### 3.1. Integration of HSE interventions into the overall management system

The incorporation of interventions into the overall management system of the process industry is crucial for ensuring effective and efficient operations. Interventions refer to actions taken to address specific issues or improve procedures within the industry. These operations may involve equipment maintenance and upgrades, process optimization, and implementing safety measures. Integrating interventions into the management system entails aligning them with the overarching aims and objectives of the organization and integrating them into existing processes and procedures [117–119]. In considering combining interventions, keep the following variables in mind:

- It is essential for interventions to align with the process industry's strategic goals. They must focus on particular issues or possibilities crucial to the organization's goals, such as increasing productivity, lowering expenses, improving safety, or meeting regulatory requirements.
- It is important to perform a comprehensive risk assessment to identify the critical areas that require intervention. This assessment should consider safety hazards, operational risks, environmental consequences, and financial implications. The interventions can be effectively targeted and implemented by prioritizing actions based on their potential impact and the level of risk they mitigate.
- It is crucial to engage in effective planning and prioritization when integrating interventions. Develop a comprehensive strategy outlining the necessary interventions, including their timelines, resource requirements, and responsibilities. Prioritize the interventions based on their significance, urgency, and feasibility. Considering the interdependence and potential conflicts between interventions is important to facilitate a seamless implementation process.

- It is essential to address change management to effectively integrate organizational interventions. Implementing a change management strategy that includes factors like interaction, participation of stakeholders, education and training, and encouragement measures is critical. It is critical to make sure workers comprehend the goal and advantages of the interventions and have the requisite abilities to implement and sustain the changes. By incorporating these components, the organization can facilitate a smooth transition and increase the likelihood of successful intervention integration.
- It is necessary to recognize that integrating interventions should be an ongoing and continuous process. Foster a culture of continuous improvement by establishing feedback systems, monitoring key performance metrics, and conducting regular evaluations. Analyze the collected data and make necessary adjustments to the interventions to enhance their effectiveness and adapt to evolving industry conditions. By embracing this approach, the organization can optimize the integration of interventions and remain responsive to the changing dynamics of the industry.
- It is important to emphasize the significance of documentation and knowledge sharing when integrating interventions. Thoroughly document the interventions, including the methods of implementation and their outcomes. This documentation is valuable for future reference and offers insights into successful approaches. Encourage information exchange and facilitate learning from past experiences throughout the organization, promoting a culture of innovation and continuous improvement. By fostering knowledge sharing, the organization can leverage prior knowledge and experiences to enhance the effectiveness of interventions and drive innovation forward.
- It is vital to establish appropriate metrics and performance indicators to monitor the impact of interventions on the overall management system. Regularly evaluate initiatives' success and alignment with the organization's objectives. Utilize the gathered data to make informed decisions, such as scaling up effective interventions or modifying those not producing the desired outcomes. By leveraging this feedback loop, the organization can continuously improve its intervention strategies and ensure they effectively contribute to the desired goals.
- In summary, it is evident that integrating interventions into the overall management system of the process industry brings several benefits. It enables organizations to enhance operational efficiency, elevate safety standards, lower costs, and ensure compliance with regulations. By incorporating interventions, organizations can take a proactive approach to addressing challenges and capitalizing on opportunities for growth and innovation. This integration fosters an environment conducive to continuous improvement and enables the process industry to optimize its performance and achieve sustainable success.

### 3.2. Factors influencing the sustainability of HSE interventions over time

Several factors influence the sustainability of interventions in the process sector see Refs. [120,121] Following are a few key variables that can affect the long-term viability of interventions:

- It is crucial to consider the environmental impact of various activities as they greatly affect sustainability. Sustainable initiatives prioritize conserving resources, reducing emissions, and preventing pollution. Companies must properly examine the environmental impact of their production activity and take measures to mitigate any negative impacts.
- It is essential to recognize that economic viability is fundamental to providing the long-term sustainability of interventions. Initiatives that are not economically feasible may not be long-term sustainable. Companies must evaluate the costs of implementing and sustaining interventions, such as equipment, materials, personnel, and operations. To ensure economic feasibility, these measures' financial advantages and payback times must be evaluated.
- It is important adherence to and recognizes environmental regulations, which is crucial for the sustainability of the process industry. Interventions should align with existing environmental norms and standards while considering potential regulatory requirements. Noncompliance with these regulations can result in penalties, legal issues, damage to reputation, and even operational disruptions. Therefore, it is imperative to develop sustainable solutions that meet the necessary regulatory standards.
- Improvement in technology contributes to the long-term viability of programs. New technologies that can enhance efficiency, reduce waste, and improve environmental performance develop regularly in the process sector. Regular technological progress monitoring is required to identify improvement chances and upgrade existing initiatives.
- In summary, considering these factors and incorporating sustainable practices into their operations, companies in the process industry can improve the durability and efficiency of their interventions, thereby making a valuable contribution to long-term sustainability.

## 4. Conclusions

This research demonstrates that interventions substantially influence the well-being, safety, and environmental aspects of the process industry. Highlighting the significance of interventions requires acknowledging that they are not a one-time solution but an ongoing procedure needing constant monitoring and review. Companies must prioritize the well-being of their workers along with their surroundings by implementing standard operating procedures, conducting training programs, and utilizing technology have proven effective in decreasing workplace accidents, injuries, and occupational illnesses. This approach assists the process industry drives towards having safer working conditions for workers while also promoting a sustainable ecosystem.

Furthermore, it is crucial to consider the economic viability of initiatives to guarantee their long-term sustainability. Companies should thoroughly evaluate the costs of implementing and sustaining initiatives, financial advantages and payback periods. This assessment ensures that initiatives are economically feasible and capable of maintaining long-term viability. Regulatory compliance is

an essential aspect that must not be underestimated. Companies must adhere to environmental regulations and standards to prevent fines, legal complications, reputational damage, and operational disruptions. Companies must anticipate future regulatory requirements and proactively develop sustainable solutions that meet and exceed these standards.

Moreover, it's imperative to incorporate innovative technology to improve the efficiency and longevity of interventions critically. Due to the constant evolution in process industries, closely monitoring technological progress grants companies a unique opportunity to minimize waste and enhance environmental performance through reduced resource usage. Optimal reliability on these considerations while consistently implementing eco-friendly practices in everyday operational procedures leads the way towards long-term sustainability. This has positive implications for the well-being, safety, and environment and guarantees the industry's ongoing prosperity amidst changing and emerging challenges.

It's essential to recognize that while this research offers valuable insights, it is not without limitations. Some notable constraints associated with this theoretical research include the lack of empirical data, challenges in generalization, limited contextual understanding, and difficulties in quantitative measurement.

- I. Lack of Empirical Data: Theoretical research relies heavily on existing theories and models, which may limit direct access to real-world empirical data. This constraint can impede the validation of theoretical propositions using actual industry data.
- II. Generalization Challenges: The focus on abstract concepts and general principles in theoretical research poses challenges in directly applying findings to specific industries or interventions within the process industry.
- III. Limited Contextual Understanding: Theoretical research might not fully capture the nuanced contextual factors specific to the process industry, including its unique challenges, regulations, and operational intricacies.
- IV. Difficulties in Measurement: The challenge of quantitatively measuring theoretical constructs can be complex, making it difficult to operationalize these concepts for empirical testing.

To address these limitations, the authors are contemplating augmenting this research with a case study and involving industry stakeholders to ensure practical relevance and applicability in the future. This approach will concentrate on specific interventions within a particular process industry to gain a nuanced understanding of their detailed impact on health, safety, and environmental outcomes. Another prospective avenue is the adoption of a Mixed-Methods Research approach to achieve a more comprehensive understanding. This could involve the collection of quantitative data through surveys and qualitative data through interviews. The integration of diverse research methods has the potential to bolster the robustness of the findings and enhance their impact on industry practices.

#### 4.1. Recommendations

- It is crucial to emphasize the significance of prioritizing the health and safety of workers within the process industry and operational environment. This can be achieved by implementing comprehensive safety protocols, delivering appropriate training programs, and ensuring the utilization of protective equipment. Regularly monitoring and evaluating occupational hazards should be conducted to identify potential risks and take necessary preventive measures.
- It is necessary to highlight the significance of ongoing evaluation and adoption of innovative technologies in the process industry.
- It is essential to acknowledge the importance of conducting frequent impact assessments to properly gauge the effects of interventions on health, safety, and the operational environment. Through rigorous analysis of these factors, we gain valuable insight that can guide future decision-making processes while identifying those areas which require further attention or targeted improvements.

No data was used for the research described in the article.

#### CRediT authorship contribution statement

**Chizubem Benson:** Writing – original draft. **Izuchukwu Chukwuma Obasi:** Visualization. **Damola Victor Akinwande:** Visualization. **Chinonso Ile:** Visualization.

#### Declaration of competing interest

I Benson Chizubem declare that there are no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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