Chapter

Industrial Safety Management Using Innovative and Proactive Strategies

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Abstract

Safety is considered a top priority due to its significance in safeguarding human lives and properties, especially in high-risk industrial sectors such as aviation, oil and gas, construction, transportation, steel manufacturing, and mining industries. These industries are plagued by workplace injuries, illnesses, and fatalities because of the dangerous work environments. As such, it is very vital to integrate safety into every work process in any industrial environment just like quality is built into products and services. It is important to establish and execute an effective safety management system to prevent the risks of irreversible accidents. This chapter begins with a background to safety management in industrial engineering and a discussion of the various issues of industrial safety management. It follows with an extensive description of existing and commonly used safety performance measurement methods. Several case studies are used to explain the methods and explore the important application areas relevant to most industrial sectors. The techniques and tools for safety data collection, analysis, and sharing are introduced together with their applications for safety management. The last section explains how emerging technologies can be implemented in most industrial sectors to enhance safety management.

Keywords: emerging technologies, hazard identification, safety management

1. Introduction

Industrial work environments are often characterized by dynamic resources including interactions between mobile equipment and pedestrian workers. The hazardous work environment characteristic of industrial facilities is evident in the high rates of workplace injuries and fatalities experienced regularly. These high-risk industries include construction, steel manufacturing, oil and gas, aviation, agriculture, forestry, fishing, and hunting, etc.

For instance, the construction industry remains one of the most hazardous and unsafe industries with fatality and incidence rates considerably higher than the all-industry average in many countries [1–4]. Incident statistics indicate that construction workers have consistently incurred more fatal injuries than in other industries. Despite the efforts to improve safety performance, the construction sector continues to account for disproportionate injury rates accounting for the most on-the-job fatal injuries. In the United States, construction remains the most hazardous industry in terms of the aggregate number of fatalities [1]. Thus, innovative intervention strategies are being continuously explored by researchers and practitioners to enhance management controls as well as modify human behavior and work environment to improve construction safety.

Steel manufacturing is one of the most hazardous industries because of its complex socio-technical system. The steel manufacturing process involves the use of high technology and physical labor, making safety management a complicated task [5]. Members of the U.S. steel manufacturing industry continue to experience a significant number of injuries, illnesses, and fatalities [6]. The combination of intricate technology and physical labor creates a complicated challenge for safety managers in steel manufacturing [5].

The fundamental goal of measuring safety performance is to create and implement intervention strategies for potential avoidance of future accidents. Recognizing signals before an accident occurs offers the potential for improving safety; many organizations have sought to develop programs to identify and benefit from alerts, signals, and prior indicators [7]. Traditional measures of safety performance rely on some form of accident or injury data [8], with actions being taken in response to adverse trends in injuries [9]. Many organizations rely heavily on failure data to monitor performance. The consequence of this approach is that improvements or changes are only determined after something has gone wrong [10]. In most cases, the difference between whether a system failure results in a minor or catastrophic outcome is purely a matter of chance.

Effective management of major hazards requires a proactive approach to risk management, so information to confirm that critical systems are operating as intended is essential [11]. Transitioning the emphasis in favor of leading indicators to confirm that risk controls continue to operate is an important step forward in the management of major hazard risks [10]. Accurate safety performance measurement facilitates the evaluation of ongoing safety management and the motivation of project participants to improve safety [12].

The ability to collect, analyze and disseminate safety information using a large amount of useful data from leading indicators can allow for hazardous events and conditions to be efficiently mitigated and controlled before a lagging indicator occurs [11]. In this chapter, a background to safety management in industrial engineering is presented followed by a discussion of the various issues of industrial safety management. The existing and commonly used safety performance measurement methods are extensively described. Several case studies are used to explain the methods and explore the important application areas relevant to most industrial sectors. The techniques and tools for safety data collection, analysis, and sharing are introduced together with their applications for safety management while the use of emerging technologies for enhancing safety management in most industries is discussed in the last section.

2. Safety culture

The safety culture of an organization refers to the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to and the style and proficiency of an organization's safety and health management [13]. Safety culture has been defined in a variety of ways and there is no standard definition of safety culture. This is mainly because a culture of safety has diverse meanings in different industries and people may have

Reference	Definition of safety culture
[8]	Safety culture is thought to influence employees' attitudes and behavior in relation to an organization's ongoing health and safety performance [14]
[15]	The Safety Culture is made up of a collection of individual cultures and other subcultures within the environmental constraints and promotions of the organization [15]
[16]	Safety culture is defined as a set of prevailing indicators, beliefs, and values that the organization owns in safety [16]
[17]	Safety culture is a sub-facet of organizational culture, which is thought to affect members' attitudes and behavior in relation to an organization's ongoing health and safety performance [17]
[18]	Safety culture forms a subset of organizational culture relating specifically to the values and beliefs concerning health and safety within an organization [18]
[19]	Safety culture refers to shared attitudes, values, beliefs, and practices concerning safety and the necessity for effective controls [19]
[20]	Safety culture is defined as: those aspects of the organizational culture which will impact on attitudes and behavior related to increasing or decreasing risk [20]
[21]	Safety culture is shaped by people working together in organizational structures and social relationships in the workplace. The key attributes of organizational culture are defined as organizational communication, senior management commitment and organizational learning [21]

Table 1.
Selected safety culture definitions.

various understandings in different situations. Selected examples of safety culture definitions are organized and shown in **Table 1**.

Strong safety culture has a significant impact on improving safety performance, reducing incidents, conducting a successful near-miss, and incident reporting in an organization. The growing importance of safety culture to the industry is evidenced by reports, guidelines, publications, workshops, and conferences. As an industry-led initiative, the Center for Offshore Safety (COS) defined six specific elements characteristic of a successful offshore safety culture, including leadership, respect and trust, environment for raising concerns, open communication, personal accountability, and inquiring attitude [22]. According to the European Union Agency for Railways (ERA), "Safety culture refers to the interaction between the requirements of the Safety Management System (SMS), how people make sense of them, based on their attitudes, values, and beliefs, and what they actually do, as seen in decisions and behaviors" [23]. A safety culture model (**Figure 1**) was developed by ERA to assess safety culture and identify improvable areas [23]. The model is made up of three building blocks: cultural enablers, behavior patterns, and railway safety fundamentals [23].

- Cultural enablers: those levers through which an organizational culture develops;
- Behavior patterns: those shared ways of thinking and acting which convey the organizational culture;
- Railway safety fundamentals: those core principles which must be reflected by behavior patterns to achieve sustainable safety performance and organizational excellence.

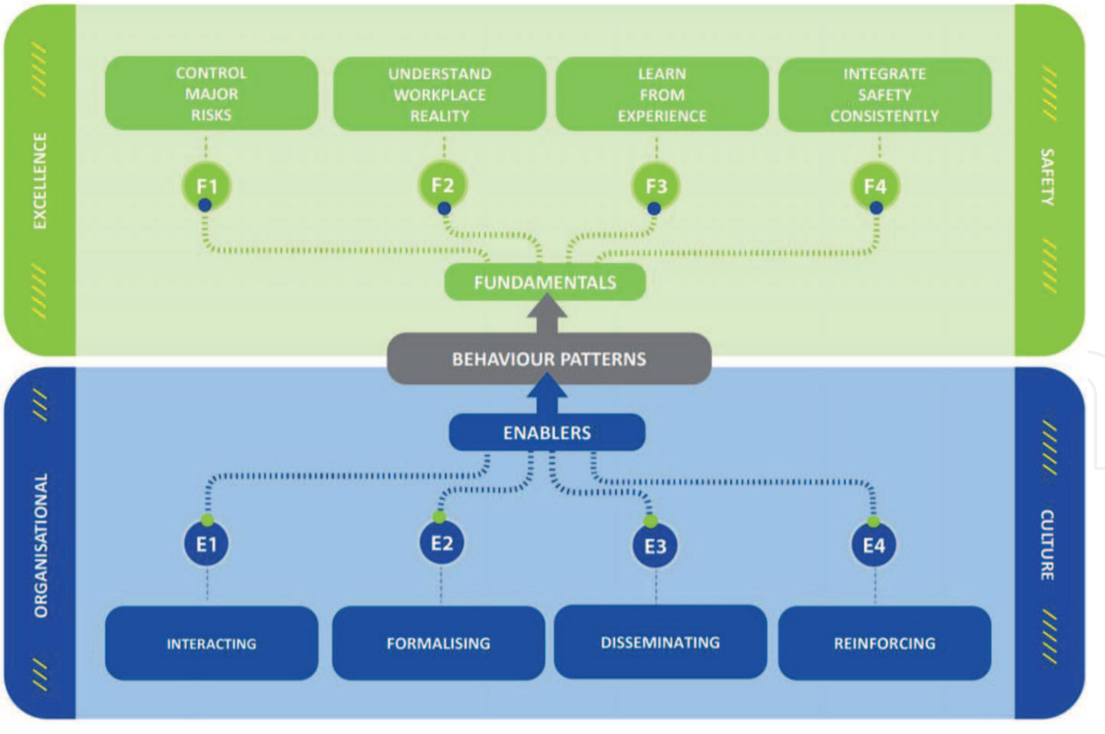

Figure 1.
European Railway Safety Culture Model 2.0: Components.

Within a positive safety culture, the organization's formal management systems and leaders' informal management practices encourage, recognize, and reinforce safe behaviors, and create an environment where employees feel responsible for their safety and the safety of their peers [14]. The largest indicator of a management's commitment to safety is the investments made for safety including discretionary safety funding [24]. Previous research investigated the correlation between safety discretionary funding of construction companies and their corresponding safety record [25]. Results suggest that increasing the amount of discretionary safety funding in a construction company can improve their incident record. Furthermore, companies that invest in safety programs, training, and employee incentives can improve their safety record [25]. Finally, results from a construction safety study found that organizational commitment throughout all levels (top management, site level, to the individual level) is the key to promoting improved safety performance [26].

3. Safety performance measurement

The primary goal of measuring safety performance in a work environment is to intervene in an attempt to mitigate unsafe behaviors and conditions that can lead to accidents. Various measures of safety performance have been used for decades and they have served a useful purpose [27]. Generally, performance measurements can either be reactive or active monitoring [10]. While reactive monitoring means identifying and reporting on incidents and learning from mistakes, active monitoring provides feedback on performance before an accident or incident occurs [28].

In the US, safety performance has traditionally been measured by metrics such as the Occupational Safety and Health Administration (OSHA) recordable injury rate (RIR); days away, restricted work, or transfer (DART) injury rate; or the experience modification rating (EMR) on workers' compensation [27]. Past safety performance has been largely measured and driven by lagging indicators (including injuries, illnesses, and fatalities), but improvements and enhancements of safety performance can be experienced through implementing safety leading indicators to measure worker safety performance [11]. Although lagging indicators will continue to be used, they have serious limitations when it comes to the prediction of the current and future safety performance of a project or work environment. This makes the need for leading indicators of safety performance very crucial [27].

The term "indicators" is used to mean observable measures that provide insights into a concept that is difficult to measure directly; a safety performance indicator is a means for measuring the changes over time at the level of safety as the result of actions taken [29]. An indicator is a measurable and operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality. An indicator can be considered any measure (quantitative or qualitative) that seeks to produce information on an issue of interest [30]. Safety indicators can play a key role in providing information on organizational performance, motivating people to work on safety, and increasing the organizational potential for safety [31].

The major distinction between leading and lagging indicators lies in the type of response that is elicited by them when the measures indicate that performance is not as desired. While in leading indicators, the response is proactive in nature with the intent of making changes in the safety process to avoid injuries, with lagging indicators, the response is reactive as a response is made after injuries have already occurred and the response is initiated to try to prevent the occurrence of further injuries [27]. Hence, the two categories of safety metrics are: (1) lagging indicators (i.e. metrics linked to the outcome of an injury or accident); and (2) leading indicators (i.e. metrics or measurements linked to preventive actions).

3.1 Lagging indicators

Lagging indicators are related to reactive monitoring which involves identifying and reporting on incidents to check that controls in place are adequate, to identify weaknesses or gaps in control systems, and to learn from mistakes [10]. They show when the desired safety outcome has failed, or when it has not been achieved [32]. Since lagging indicators might prompt response after an injury or a series of injuries have occurred, it should be evident that lagging indicators of safety performance are based on past safety performance results [27]. Lagging indicators do not provide further insights on the existing safety conditions once an accident has occurred because they do not give room for informed decision making based on continuous data collection and analysis [33]. The most commonly used lagging indicators are accident rate, lost workday injuries, medical case injuries, and experience modification rate (EMR), among others.

3.2 Leading indicators

Leading indicators are measurements of processes, activities, and conditions that define performance and can predict future results [9]. A leading indicator is the result of periodic measurements of specific safety performance. Leading indicators provide opportunities for safety managers to identify areas of safety performance that need improvement before injuries or fatalities occur [34]. Leading indicators measure the building blocks of the safety culture of a project or company. When one or more of these measures suggest that some aspect of the safety process is weak or weakening, interventions can be implemented to improve the safety process and, thereby positively impact the safety process before any negative occurrences (injuries) are sustained [9]. The common leading indicators used in industrial sectors are near miss reporting, project management team safety process involvement, worker observation process, job site audits, housekeeping program, stop work authority, safety orientation and training, etc. Leading indicators consist of both passive as well as active measures. Passive measures are those which can be predictive over an extended period while active measures are those which can initiate corrective steps in a short period. These two measures of leading indicators are further described as follows.

3.2.1 Passive leading indicators

Passive leading indicators are those that provide an indication of the probable safety performance to be realized within a firm or on a project. While they may be somewhat predictive on a macro scale, they are less effective as being predictive on a short-term basis. This implies that the process being monitored by passive leading indicators cannot generally be altered in a short period of time [27]. Measures of passive indicators are usually binary in that the organization implements them or does not [35]. The most reliable information that passive indicators provide when properly analyzed and applied is a simple qualitative measure of the knowledge or skills base of personnel which is useful in implementing a comprehensive safety management system [27].

3.2.2 Active leading indicators

Active leading indicators are those which are more subject to change in a short period. Active leading indicators can either be quantitative, but the measures can also be qualitative. Quantitative measures may be preferred as they are more objective and may result in more consistent interpretation. Nonetheless, when no other means are available, qualitative measures should not be avoided [27]. The leading indicators of safety performance essentially disclose what aspects of the safety program are going well and, if there are any weaknesses, these will be identified, and implementation of change can be initiated. Active indicators are generally continuous in that they occur at a frequency or are measures of quality of implementation [35]. Active leading indicators represent both a qualitative and quantitative measure of the actual implementation of the processes within a comprehensive safety management system [27].

4. Safety management through hazard identification

In high-risk industrial sectors, workers are constantly exposed to various types of occupational hazards due to the nature of their work and condition of the work environment. The first step in accident prevention is the identification of hazards. The improvement of safety performance requires the implementation of proactive worker hazard identification and prevention programs. In many industrial sectors, the safety performance of workers is predominantly measured based of their ability to proactively identify and respond to hazards in the work environment [36]. Hazards are related to the improper release of energy. Accidents result from the interaction of energy, equipment or materials, and one or more people, and the potential hazards associated with such interaction can be identified based on the energy sources recognition.

Being oblivious of the presence and magnitude of an energy source often results in an accident. As a result, it is important to identify highly innovative and effective hazard recognition strategies such as implementing techniques to avoid future accidents [36]. Because hazards can be caused by different energy sources, the awareness of all the energy sources is key to identifying potential hazards and creating a safe environment. The risk associated with hazardous conditions or situations in a work environment can only be analyzes for accident prevention if the related hazards can be correctly recognized or identified.

In construction, for instance, workers are constantly exposed to hazards that are difficult to measure due to the nature of the work environment and the way construction tasks are performed [28, 37]. Statistics indicate that fatalities and incidents rates in the construction industry remain significantly higher than the all-industry average in many countries. This makes the construction industry one of the most hazardous and accident-prone industries and the majority of the accidents experienced occur due to the inability of the workforce to predict, identify, and respond to hazards at the workplace [38]. The dynamic nature of construction work and task unpredictability on projects make hazard recognition difficult [39]. The energy required to accomplish work tasks on projects if released inappropriately may cause loss-of-control which can get construction workers injured [40]. The probability of accidents will increase when hazards are not identified and assessed on a typical project.

In the steel manufacturing industry, employees continuously work in highly hazardous work environments characterized by limited visibility, hazardous proximity situations between heavy equipment and pedestrian workers, and the dynamic nature of manufacturing tasks. The working conditions typical of steel manufacturing environments include increased amounts of repetitive work tasks [41], elevated temperature [42], noisy surroundings [43] and an overall rugged work environment [44]. These conditions tend to cultivate conditional and behavioral hazards that increase the probability of employees experiencing an incident in the form of an injury, illness, or fatality. The choice and the implementation of specific measures for preventing workplace injury and illness in the iron and steel industry depend on the recognition of the principal hazards and the anticipated injuries and diseases, ill health, and incidents [11]. Although hazard identification provides a useful method for mitigating hazards, the impact of specific hazards categories on injuries, illnesses, and fatalities has not been quantified [44]. To proactively identify hazardous situations and conditions, details from safety incident data can be analyzed to identify predictor variables of future incidents in steel manufacturing environments.

4.1 Energy source recognition

An injury occurs whenever energy is released from one or more of these sources and transferred to the human body. For instance, a suspended load is a source of gravity and motion because it has the potential to fall and swing. If a worker is struck by this suspended load, motion energy will be transferred from the load to the worker and absorbed by the worker's body, causing an injury. Other examples of energy sources in industrial work environments include radiation from welding, hot and cold objects and environments, compressed gas cylinders, hazardous substances, moving and noisy equipment and vehicles, and objects and bodies at height [45].

Certain hazard sources and activities may be associated with multiple hazards. For example, an electric cable on the floor may be associated with a trip hazard and an electrical hazard. Industrial work environments may contain hidden or dormant hazards that are not expected or perceived as imposing any imminent danger. Such hazards often remain in work environments as latent or stored energy for extended periods without causing any harm. However, the unexpected release or trigger of these latent sources of stored energy can result in dramatic injury and illnesses.

Because of the importance of hazard recognition, employers adopt several methods to improve hazard recognition levels. One of these methods is the retrospective hazard recognition method which is based on deducing or extrapolating knowledge gained and lessons learned from past safety incidents (i.e. accidents data) to new situations and projects [46, 47]. Despite these significant advancements, there is still a dearth of research that investigates the scientific extension and practical application of hazard energy within occupational safety [48].

5. Safety data collection, analysis, and sharing

A strong system of safety data collection, analysis, and sharing will assist the industry to understand the root causes of an event, explore existing and potential hazards, and continuously improving existing safety programs. Different countries and industries have conducted multiple reporting systems to collect, analyze, and share information with the public. For example, HSE has collected data on fatal injuries, nonfatal injuries, and ill health through the Labour Force Survey (LFS). The nonfatal injury and ill health estimates from the LFS are based on averages over 3 years. The fatal injuries data are collected based on RIDDOR (the Reporting of Injuries, Diseases, and Dangerous Occurrences Regulations) reports. In the United States, the Occupational Safety and Health Administration (OSHA) inspects the workplace to ensure compliance with minimum safety standards. If OSHA compliance officers find any violations on a site, they may issue a citation and a penalty. A company that had more than 10 employees at any time during the last calendar year must keep OSHA injury and illness records. Even if an employer is not required to keep injury and illness records, they are still required to report to OSHA within 8 hours any workplace incidents that result in death or the hospitalization of three or more employees. If there is a serious accident at a job site in which three or more workers are hospitalized or someone is killed, OSHA must be notified. OSHA will then investigate the accident.

5.1 Safety data collection

According to Section 3, safety incident data contains leading indicators (e.g. near misses) and lagging indicators (injures, illnesses, fatalities). Near-miss and incident reporting programs have been promoted and developed across high-risk industries [49]. OSHA requires employers to report all work-related fatalities and severe injuries according to OSHA Regulations (Standards—29 CFR 1904):

- All employers are required to notify OSHA when an employee is killed on the job or suffers a work-related hospitalization, amputation, or loss of an eye.
- A fatality must be reported within 8 hours.
- An in-patient hospitalization, amputation, or eye loss must be reported within 24 hours.

Besides the OSHA recordkeeping, many of the current companies in the high-hazard industries use daily reporting applications (apps) to collect the safety data from their project sites. However, those data are mainly used internally for company future development. **Figure 2** shows examples of safety data collected by the Bureau of Labor Statistics (BLS) and safety apps.

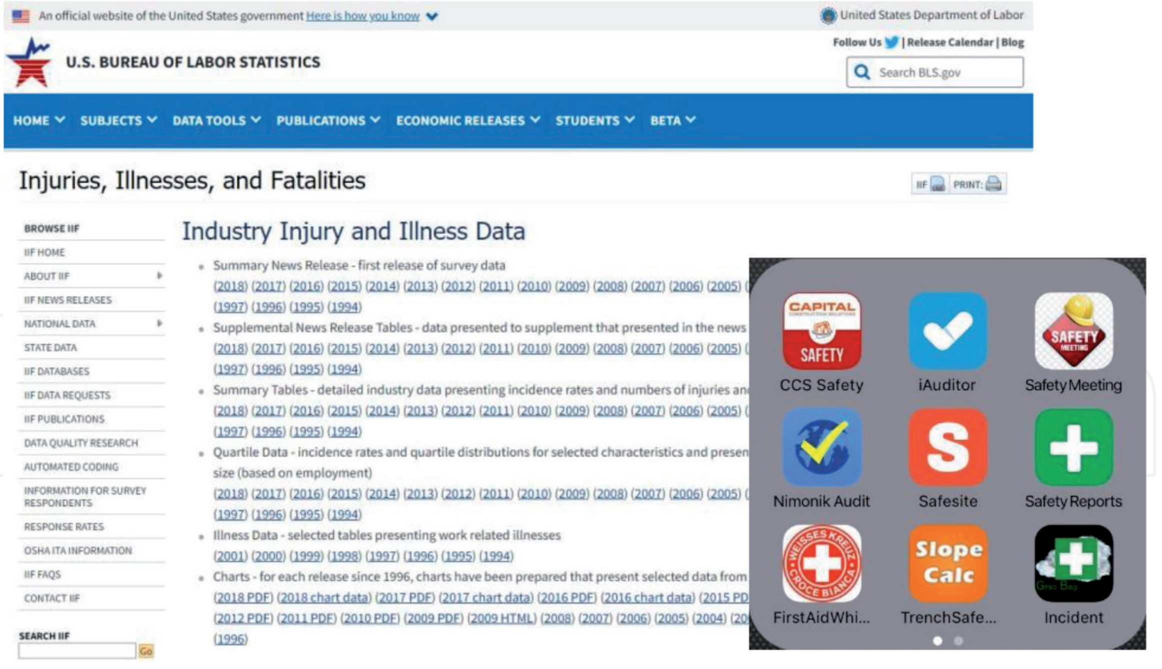

Figure 2.
Safety data collection methods (image source: https://www.bls.gov/iif/oshsum.htm and https://conappguru.com/apps/apps-for-construction-safety-2016/).

5.2 Safety data analysis

According to OSHA, the incidence rates represent the number of injuries and illnesses per 100 full-time workers and are calculated as $(N/\text{EH}) \times 200{,}000$:

$$\text{Incident rate} = \frac{(\#\text{of cases or days } \textit{per} \text{ year}) \times 200{,}000}{\text{Total employee hours } \textit{per} \text{ year}} \tag{1}$$

Where N = number of injuries and illnesses; EH = total hours worked by all employees during the calendar year; 200,000 = base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year).

The US BLS Injuries, Illnesses, and Fatalities (IIF) program produces a wide range of information about workplace injuries and illnesses. These data are collected and reported annually through the Survey of Occupational Injuries and Illnesses (SOII) and the Census of Fatal Occupational Injuries (CFOI). **Table 2** is the latest industry incidence rates (OSHA recordable case rates) from BLS.

5.2.1 EMR (cost of accidents)

An accident cost usually includes direct and indirect costs. The biggest difference is if the costs can/cannot be directly attributed to the incident. The National Council on Compensation Insurance (NCCI)'s EMR is a metric to calculate workers' compensation insurance premiums.

EMR is calculated by trends in the loss ratio:

$$\text{Loss ratio} = \frac{\text{Claims (in \$)}}{\text{Premiums payments (in \$)}} \tag{2}$$

Industry	Total recordable cases		Cases with days away from work	
	2017	2018	2017	2018
Private industry	2.8	2.8	0.9	0.9
Agriculture, forestry, fishing, and hunting	5.0	5.3	1.7	1.7
Mining, quarrying, and oil and gas extraction	1.5	1.4	0.7	0.6
Construction	3.1	3.0	1.2	1.2
Manufacturing	2.5	3.4	0.9	0.9
Wholesale trade	2.8	2.9	1.0	1.0
Retail trade	3.3	3.5	1.0	1.1
Transportation and warehousing	4.6	4.5	2.0	2.1
Utilities	2.0	1.9	0.7	0.7
Information	1.3	1.3	0.6	0.6
Finance and insurance	0.5	0.5	0.1	0.1
Real estate and rental and leasing	2.4	2.3	1.0	0.8
Professional, scientific, and technical services	0.8	0.8	0.2	0.2
Management of companies and enterprises	0.9	0.8	0.2	0.2
Administrative and support and waste management and remediation services	2.2	2.3	0.9	0.9
Educational services	1.9	1.9	0.5	0.6
Health care and social assistance	4.1	3.9	1.1	1.1
Arts, entertainment, and recreation	4.2	4.1	1.2	1.1
Accommodation and food services	3.2	3.1	0.9	0.9
Other services (except public administration)	2.1	2.2	0.7	0.8

Table 2.
Incidence rates of nonfatal occupational injuries and illnesses by selected industry and case types, private industry, 2017-2018 [50].

The average EMR is 1.0. If a company's EMR is above 1.0, the company is considered riskier than most. For example, if a company has an EMR of 1.3, that means the insurance premiums could be up to 30% higher than a company with an EMR of 1.0. On the other hand, if a company has an EMR below 1.0, the company is considered safer than most which could receive a lower premium.

To better understand the collected incident data, many statistical modeling methods were used to identify the impact factors of incidents. The following two case studies introduced how statistical modeling helps with analyzing safety leading indicators and lagging indicators.

5.2.1.1 Case study #1 (using binary logit regression)

In this case study, approximately 2300 reported incidents at an active steel manufacturing facility in the U.S. between January of 2010 and August of 2016 were input into statistical predictive models [44]. The objective of this research is to identify specific variables using statistical models that increase the probability of an unsafe event or condition within a steel manufacturing facility [44]. Due to the organization and metrics recorded for the steel manufacturing safety incident database analyzed in this research, a statistical prediction model - Binary Logit Model was selected for data analysis. The probability denoted Pr(Y), is assumed to be determined by a set of independent variables (X_1, X_2, ..., X_j), and a corresponding set of parameters (β_0, β_1, β_2, ..., β_j). The dependent (Response) variables include OSHA Recordable, Lost time, First Aid, Property Damage, Environmental Incident, and Fire. The independent (predictor) variables describe the incident occurred situations [44]. Variables can be divided into six categories: summer indicator (June, July, or August), task performed indicators (operating or driving), moving equipment indicators (crane, truck, forklift, or trailer), mobile equipment indicator, location indicators (roll shop, coil yard/ disposition, cut to length shop, west gate, water system, or melt shop), and preliminary cause indicators (defective equipment or personal responsibility) [44]. Findings from the regression analysis suggest that a positive correlation exists between incidents and summer months. One possible explanation is that employees have higher possibility to be distracted and fatigued due to high temperature. Results also suggest that injuries have a positive correlation with pedestrian employees near pieces of moving equipment [44]. Mobile equipment including trucks, forklifts, and truck and trailer combinations have a positive correlation with an incident [44].

5.2.1.2 Case study #2 (using text mining)

This study analyzes OSHA inspected fatalities data in the past 5 years from June 2014 to Aug 2018 with a total of 4769 accident records. Text mining techniques were deployed in this study for hazard report extraction [36]. **Figure 3** shows the research framework.

The incident description variables were processed using the R package 'openNLP' [51]. This package allows users to clean text data and perform machine-learning-based entity extractions. An energy source recognition method was then used to categorize the data into 10 energy source groups. Several corresponding key words were identified based on the energy source groups (**Table 3**). For example, "Worker died in fall from ladder" should be classified to Gravity due to the presence of the key term "fall". The findings show that gravity, motion, mechanical, and electrical related incidents have the largest percentage rate (**Figure 4**). This presented data analysis method can help with predicting future events, preventing reoccurrence of similar accidents, making scientific risk control plans, and incorporating hazard control measures into work tasks.

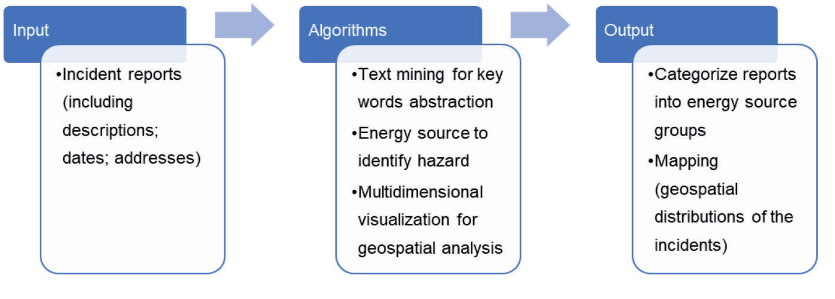

Figure 3.
Research framework of incident analysis using text mining and geospatial mapping [36].

Energy source	Corresponding key words
Gravity	Fall, excavation, collapsing, elevated, uneven, open holes
Motion	Confined space, movement, struck by, caught in, caught between, lifting
Mechanical	Rotating, compressed, conveyor, belt, motors, power tool, hand tool
Electrical	Electrocuted, power line, light fixtures, circuit panel, wiring, batteries
Pressure	Piping, cylinders, control liners, vessels, tanks, hoses, pneumatic, hydraulic
Temperature	Ignition, cold, hot, fumes, heat, molten slag
Chemical	Vapors, corrosive, gas, carbon monoxide, asphyxiation, chemical, toxic, sulfur dioxide
Biological	Animals, bacteria, viruses, insects, blood-borne pathogens, contaminated water, food
Radiation	Lighting, welding, arc, flash, X-rays, solar rays, microwaves, sunlight
Sound	Noise, vibration

Table 3.
Categorization of data into 10 energy source groups.

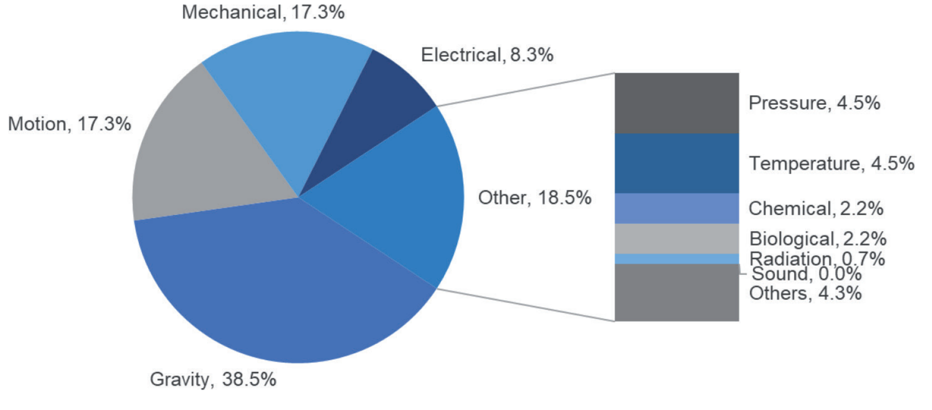

Figure 4.
Distribution of the energy sources [36].

6. Emerging technologies

6.1 Safety training through computer-aided technologies

The development of virtual reality (VR), augmented reality (AR), and mixed reality (MR) have embedded worker training systems and become significant cost-effective and safer ways to educate workers. The immersive VR/AR/MR environments within computer-generated simulations have also gained popularity in safety training to identify the potential hazards as well as educate moving vehicle operators on the job site. Hazardous construction scenarios can be simulated interactively with the working environment, workers' behavior, high-risk equipment, and working sequence [52]. Researchers also found that many VR/AR systems had been proved as efficient, usable, applicable, and accurate approaches in hazard identification, safety training, and education, and safety inspection [52].

6.2 Integrating BIM and safety

Numerous studies and industrial applications evidenced that safety and BIM integration can assist in safety planning and execution of projects, for example to automatic checking of construction models and schedules for preventing fall-related accidents; automated scaffolding-related safety hazard identification [53], visualization [54], and prevention [55], blind spots identification and mapping [56], path planning [57], near-miss information reporting and visualization [58], towel crane location optimization [59], etc.

6.3 Proximity detection devices

Many proximity avoidance systems have been developed by utilizing various technologies, such as an ultrasonic-based sensor [60], radio-frequency identification (RFID) sensing technology [61–63], radar [60, 64], GPS [65, 66], and magnetic field generators [67], to prevent contact accidents, particularly for accidents due to being struck by equipment. Most of these technologies provide some form of warning signals to workers when they are close to heavy equipment. These signals could be visual, vibratory, or audible warning signals [68].

6.4 Wearable sensing devices

A wide range of wearable devices has been applied across different industrial sectors including health care, manufacturing, mining, and athletics [69]. Some of these devices have proven to be very useful and beneficial to these industries and efforts are being made by both researchers and industry practitioners to improve on these technologies and learn from their initial implementation [70]. With the attention being gained by wearable devices worldwide, mobile devices are becoming part of everyday life and the number, types, and forms of wearable devices are increasing exponentially in recent years [71]. The most widespread adoption and implementation of wearable devices have been in the healthcare industry for the continuous monitoring of a user's physiological status [72]. For instance, wearable devices are used in the healthcare sector by patients personally to continuously monitor their physiological parameters and manage their health and well-being on a personal basis, or grant physicians remote access to their health data and receive personalized medical care [73]. Similarly, wearable devices incorporated with sensors such as the GPS, heart rate monitors, and pedometers are widely used in sports and fitness for tracking performance through unobtrusive and noninvasive monitoring and measurements [69]. Wearable sensors are integrated into a multitude of equipment used by professional athletes to monitor and measure their performance and safety [74]. For instance, sensors are incorporated into the helmets of National Football League (NFL) players to detect concussions and wired smart compression shirts are used to measure arm movement, and techniques are deployed to determine a pitcher's effectiveness in Major League Baseball (MLB). These different categories of wearable sensing devices can be efficiently deployed for safety and health data collection and analysis to provide real-time information to workers in industrial environments for accident prediction and prevention.

7. Conclusions

This chapter has discussed multiple industry safety-related topics including safety culture, hazard identification, safety leading and lagging indicators, safety data collection, analysis and sharing, and emerging technologies that can be embedded in safety management, training, and design. Multiple case studies and references were introduced to explain the different safety topics. Many more safety topics were not/briefly discussed in this chapter but still very important to know, for example, safety laws and regulations, design for safety, safety activity analysis, safety and productivity, heavy equipment management, occupational health illness-related topics, etc.

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