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# Implementation of Safety Management System in Managing Construction Projects

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***Abstract:***
The construction industry encounters high fatality and injury rates and is far away from achieving a zero-injury goal. Thus, effective safety management systems are critical to ongoing efforts to enhance safety. An appropriate definition of safety management systems is required, and therefore the elements included during a safety management system should be identified to be employed by practitioners to enhance safety. A variety of safety management systems are introduced by researchers and organizations. Most have been developed based on the root causes of fatalities and injuries within organizations. This paper gives an overview about different safety management systems in various fields to identify the similarities and differences in the systems. The objective of the review is to demonstrate the state-of-the art research on a spread of safety management systems and related different methods of measurement. This paper also includes background studies of developing safety management systems. The primary contribution of this review to the body of data is providing insights into existing safety management system and their critical elements including appropriate methods of safety performance measurement, which may enable owners, contractors, and decision makers to settle on and implement elements. This paper also includes application of sensors based technology in safety management of construction industry.

**Keywords**: - **Safety Management, System, SMS, housing industry, Safety Performance, Measurement**

## I. INTRODUCTION

The construction industry is one among the foremost hazardous industries. Despite the many improvement since the Occupational Safety and Health Act of 1970, workers still experience high injury and fatality rates as compared to other industries. There are more than 50,000 fatalities reported every year in the construction industry around the world. In the United States, the number of fatal injuries in construction increased by 16% from 2011 to 2014. The construction industry is way from reaching the goal of zero injuries.
The death rate for construction workers seems to be significantly higher than rates around the world. Lack of uniform parameters globally makes the comparison becomes difficult. As an example, studies include hazardous material waste cleanup, but European countries usually do not. The German death rate doesn't include steel erection. The accuracy of this data is often argued. Injury observation systems could have problems at either employee level, organizational level, or both. With the primary case, the worker should inform his/her employer. If this does occur, there is no record of it. Second, organizations must accurately record injuries in the Occupational Safety and Health Administration (OSHA) log of work-related injuries and illness in form 300 based on OSHA guidelines. If the info for the logs isn't accurate, then it results in flawed data within the BLS. The development of sensor-based technologies has hugely improved information collection, data transmission and processing, which may function the inspiration of the modernization of construction safety management. After nearly 20 years of development, sensor-based technologies have facilitated the transformation from experimental exploration to practical applications. The applications of sensor-based technology in construction safety management became the main target of current research. Since the varied safety risk factors are endless in many aspects of building construction, construction safety management includes a really broad range of topics. It is hard to offer a really clear definition and scope for construction safety management. Some scientists divided construction safety management into a pre - construction stage and a construction stage. In the former stage, potential safety hazards are usually identified supported experts' or managers' experience and eliminated through necessary preventive actions. In the latter stage, accidents are prevented by monitoring workers, machinery and therefore the whole environment on site. Nevertheless, within the process of exploring simpler safety management methods with enhanced safety concept, it's realized that construction safety management shouldn't be limited to merely the construction phase, but slowly proceed during within the

full building life cycle, conducting a comprehensive and thorough safety management. Hence, supported the appliance range of various sorts of sensor-based technologies within the field of construction, this paper divides construction safety management into six aspects intimately , including accident forewarning systems, safety route prediction and planning, hazard detection, etc.

In practice, hardware and software in processing are the 2 major factors restricting sensor-based technology. Along with the increasingly in-depth research and advanced experience of utilizing sensor-based technology in some countries and regions, it's not hard to understand that the event of sensor-based technology often falls into the contradiction between the restrictive factors. In actual use, managers usually allocate limited resources to just one of the 2 respects, counting on which one can cause larger gains. Under the circumstances, stressing the one-sided technical advantages and neglecting its defects inevitably weaken the sensible performance of sensor -based technology in construction safety management. How to seek a correct balance between hardware and software in processing is significant for promoting any sensor - based technology.

## II. LITERATURE REVIEW

The term “safety culture” first was set in motion by a post-accident review meeting after the Chernobyl disaster in 1986. Poor safety culture is recognized as a big think about any accident occurrence. Researchers and organizations have defined safety culture differently, yet the ideas of all are similar. In addition, all identify safety culture as essential for organizations to manage safety aspects of operations.

One of the possible reasons that research about safety gets significant attention among construction firms might be the value of accidents, both directly and indirectly. Although fatalities and injuries in construction are very high as compared to other industries, there are few cost estimations about injuries and fatalities available. The total cost of fatal and non-fatal injuries was estimated to be around $10.5 billion in 2002, or about $25,000 per case. Injury compensation payment that construction workers receive is about double the quantity that workers in other industries receive. Generally, construction accident costs range from 7.9% to fifteen of the project cost. The hidden cost of accidents amounts to 35% of total accident cost and hidden costs could vary between 2% to 98% counting on the accident type.

Costs related to each accident are often categorized in three types. Variable costs vary with the amount of missed days that the corporate pays for the lost wages. The second category of cost is a fixed cost. These costs the corporate for each accident thanks to administration and communication expenses. The third one may be a disturbance cost that depends on the importance of the injured person’s role within the company. The purpose of the paper is to review the state of data regarding safety management systems in several organizations also as introducing active and passive methods of safety performance measurement in construction. Background study and model development of multiple safety management system also as their elements are going to be discussed intimately. This paper is often employed by practitioners so as to implement safety management system with appropriate methods of measuring the weather within the system. It can also be beneficial for researchers working in related fields.

## III. METHODOLOGY

### 1. Application Trends of Sensor-Based Technology

The placement of sensor-based technology applied in construction safety management is shown as Figure 3. The most widely used technique is RFID, with which 28 studies are conducted. Wireless sensor networks (WSNs) ranked second (23 times), followed by vision-based sensing (19 times) and UWB (15 times). The least used methods are WLAN and ultrasound, with four papers each. By percentage, RF locating sensor-based technologies (RFID and UWB) account for 41.1%, followed by sensors and WSN (22%) and vision-based sensing (16.6%). Among these three sensor-based technologies, sensors and WSNs are a sophisticated instrument which is within the transitional stage from development to maturity, while RF locating sensor-based technology is that the most developed and widespread technique, and it consequently attracts more attention. Though vision-based sensing may be a traditional technique, it's the potential to be applied to brand-new fields. The reason is that with the event of machine learning and computer vision in image processing, the knowledge within the images or videos, which can't be identified by professionals, can be read and recognized by specific algorithms instead. Compared with the past condition, these applications are brand-new fields and helpful to reinforce construction safety management. Therefore, researchers are still dedicated to exploiting this system.

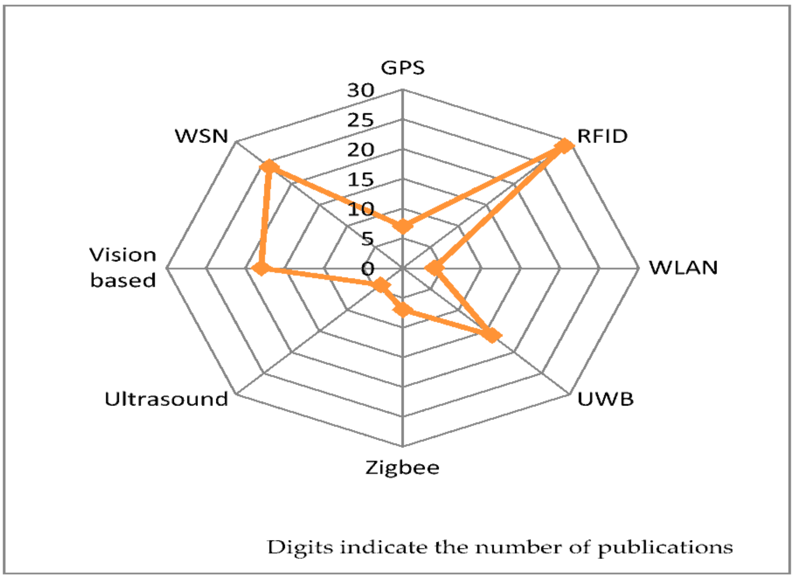


Figure 1: Application trends of sensor-based technology

## IV. OVERVIEW OF SENSOR BASED TECHNOLOGY

### 1. Locating Sensor Based Technology

#### 1.1. GPS

GPS, named the global positioning system, consist of satellites, ground control stations and user receivers. Owing to its capacity of providing 3D coordinates including points, lines and planes during a fast, accurate and efficient way under all-weather circumstances, it's been widely utilized in different fields, e.g., geodesy, photogrammetry, marine surveying and mapping. GPS has also been promoted greatly in construction safety management within the previous couple of decades. Besides its uses in engineering surveys and monitoring the deformation in buildings or building components, it's been developed in safety monitoring of building construction, including machinery equipment and construction materials. GPS is suitable for tracking objects in outdoor environments; however, it doesn't work well indoors with obstacles like basements, tunnels, culverts, etc. The accuracy and efficiency decrease evidently once the signals are blocked in such situations. Pointed out that the typical error in tracking a cement mixer truck, during a large dense populated area in Hong Kong, was but 10 m employing a combination with Global Positioning System, dead reckoning vehicle navigation and Bluetooth beacons. Pradhananga and Teizer reported a mean error of 1.1 m when locating equipment with GPS in an open area, but it increased to 2.15 m and 4.16 m in the presence of nearby obstacles.


Figure 2: GPS Sensor

### 1.2. RFID

RFID is brief for frequency identification, which identifies a selected target through radio signals. It is able to read and write corresponding data without mechanical or optical contact with the identification system. RFID consists of tags, readers and antennas.

Because it's ready to locate single or multiple targets accurately in static or dynamic indoor environment, RFID has been widely used in construction safety management, like AD, HI, ISM and AFS. Song found that the typical error of 2D positioning with RFID was 3.7m. The onsite experiments conducted by Razavi and Moselhi showed the typical positioning error was about 1.3 m in indoor environments. In practice, the accuracy of RFID are often further improved by promoting relevant algorithms or adopting different locating methods.


Figure 3: RFID Sensor

### 1.3. WLAN

Wireless local area network (WLAN) may be a data transition system using RF technology. WLANs can access the network in any point within the coverage area of wireless signals and calculate the target's position from the strength of the detected signal. The positioning system supported WLAN requires deployment of wireless signal transmitters, and therefore the target must be within the signal coverage area, thus limiting its usability within the dynamic and complicated construction site. In practice, the obstacles may hinder or maybe reflect the electromagnetic signals, affecting the WLAN's positioning accuracy, and then limit the event of WLAN in construction site. Khoury and Kamat tested the accuracy of WLAN positioning system within the laboratory, showing a mean error of 2m. Taneja reported that the positioning error ranges from 1.5 m to 4.5 m with a credibility level of 95% for static targets and about 7.6 m for dynamic ones with a credibility level of 95%.


Figure 4: WLAN Sensor

### 1.4. UWB

Ultra-wideband (UWB) may be a wireless positioning technique newly-developed in recent years. It has an honest application potential within the field of wireless indoor positioning. UWB takes advantage of ultra-wideband signals that are suitable for high-speed and short-range wireless transition thanks to their wide spectrum range. Compared to other narrow-band transition systems, it's less susceptible to multipath interference, thus it is the potential of real-time tracking for multiple targets with high sampling speed, high accuracy and low energy consumption.


Figure 5: UWB Sensor

### 1.5. Zigbee

Zigbee may be a two-way wireless communication technique with the characteristics of short distance, low complexity, low energy consumption, low transition speed and low costs. It is usually used for data transition among various electronic devices. Zigbee is widely favored by the researchers in China and in recent years is becoming a hot technique for conducting DOM in locations like tunnels, roadways and underground mines. On the opposite hand, scholars from other countries have explored its application potential by combining it with other positioning techniques like RFID and WSN instead of the utilization of Zigbee alone in AP, AFS, etc. Meng reported a mean error of 0.77 m when acquiring personnel position data in coal mines. Shen designed an automatic tunnel-boring-machine positioning system supported Zigbee and tested its performance. The test was conducted by the designed system and a specialist surveyor independently. The differences between the 2 surveying were but 2 mm, verifying the accuracy of the designed system.


Figure 6: Zigbee Sensor

### 1.6. Ultrasound

An ultrasound positioning system uses sound speed and transfer time to calculate the space between the measured point and a hard and fast point, and identify the target with triangle location method. The accuracy can usually reach centimeter level and therefore the technology is mature and low cost. However, ultrasound positioning systems have some limitations. Cricket is a mature ultrasound positioning system. It requires the targets to hold signal receivers and therefore the signal transmitters mounted on walls or ceilings. In order to affect the insufficient number of signal transmitters, the system applies RF as a backup method to supply positioning data. Tests showed the positioning error was 10 cm and therefore the orientation accuracy was 3 degrees. Skibniewski and Jang employed a mixture of ultrasound and RF to trace the development material during a construction site, achieving an accuracy of but 0.2 m with 80% credibility level starting from 1 m to fifteen m under line-of-sight conditions. Another set of experiments showed that the typical positioning accuracy was 0.97m.


Figure 7: Ultrasound Sensor

**2. Vision-Based Sensing**

Vision-based sensing uses imaging sensors to gather photos or videos. The collected data is then analyzed with specific algorithms to perceive and understand the encompassing environment. In vision-based sensing, the target does not require to carry any device. The technique itself can meet the positioning requirements during a relatively large area. However, the vision-based sensing is additionally susceptible to the impact of surrounding environment, like lighting condition and background color. In practical use in most countries round the world, including China, the appliance of vision-based sensing is restricted to the elementary level, namely fixing video surveillance systems to transmit images or videos of varied construction scenes to a surveillance center. Professionals are hired to spot useful information from images or videos and make decisions. This level is way from intelligent thanks to the low degree of data utilization and low accuracy of identification, leading great deal of data being unused or maybe ignored directly.

To rectify the dilemma in practical application, foreign research has focused on the development of algorithms to replace manual supervision so as to read and understand the useful information from images quickly and accurately. Though under some circumstances, the particular effect of some algorithms isn't as satisfactory as desirable, e.g., the machine learning in image processing isn't as accurate as human interpretation, the unceasingly improving algorithms and advances in technology will eventually overcome the present obstacles. Since there is a huge amount of information in images or videos neglected by humans but that can be read and understood by algorithms, it provides a foundation for the application of vision-based sensing in construction safety management, like AP, SD, HI, ISM, etc.

**2.1 Wireless Sensor Network**

The sensors applied in construction safety management mainly include temperature sensors, displacement sensors, light sensors, glass fiber sensors and pressure sensors. They play an important role in real-time monitoring of structures or structural components. Sensors usually acquire information and store data during a passive manner and can't read and understand the collected information proactively. In practice, wireless sensor networks are a correct thanks to turn passivity into initiative, and have thus become one among the research hotspots in sensor applications.

**2.2 Sensors**

(1) Temperature sensors: The main applications of temperature sensor include shrinkage crack monitoring for mass concrete construction, concrete curing, assisted management for winter construction and freezing method construction and temperature monitoring of structural components for improving the installation accuracy.

(2) Displacement sensors: the main applications of displacement sensors include building inclination monitoring, building subsidence monitoring, geological prediction and geological hazard pre-warning.

(3) Light sensors: Light sensors are mainly used for nondestructive examination of structural components, including concrete constructions, pile foundations, welding seams in steel structures, etc.

(4) Glass fiber: sensors glass fiber sensors are widely applied in long-term monitoring for structural safety. They are usually integrated into a WSN in order to turn the entire monitored object into a sensing structure. These sensors are often used for monitoring strains, deformations and cracks of structures, and safety evaluation for mass concrete constructions. For example, the glass fiber sensors are utilized in the health monitoring and safety assessment of the Three Gorges Dam and a few bridges in China.

(5) Pressure sensors: Pressure sensors are useful in structural load measurement. They have been used for monitoring roads, bridges and buildings, especially in pre-stressed engineering, testing end bearing capacity of pile foundations.

**V Efficacy of Safety Management Systems**

The main objective of developing and implementing safety management systems is to enhance safety performance. Bottani et al. (2009) conducted an empirical investigation of safety management systems to ascertain whether the security performance among adopting and non-adopting firms statistically differs. They collected data from 115 companies from both groups of adopting and non-adopting firms. Total five parameters were evaluated; definition of safety and security goals and communication to employees, risk data updating and risk analysis, identification of risks and definition of corrective activeness, and employees training. Industries included during this study were agriculture, manufacturing, building, commercial, and another field. The results of the study conclude that;

- Adopters got higher scores regarding determine safety and security goals and communicate to employees
- Adopters got higher scores with regard update risk data
- Adopters earned higher score with reference to assess risks and define corrective actions
- Adopter companies have significantly higher score regarding employee training

There are multiple studies that have investigated the performance of safety management systems. Most have fully or partially approved the performance of a security management system. Australian Transportation Safety Bureau has reviewed the effectiveness of a security management system. Australia's aviation, marine, and rail industries have implemented safety management system recently. The objective of the study was to assess the efficacy of implementing safety management systems supported research literature. The study concluded that well-implemented safety management systems could enhance safety performance. However, the review demonstrates that there is a scarcity of research regarding safety management systems in high-risk transport domains. Though safety management systems are linked to safety outcome supported many researchers and organizations, Gallagher et al. (2003) stated that the connection between safety management system and safety outcome is ambiguous and invalid.

## VI Applications of Sensor-Based Technology in Construction Safety Management

Though it's hard to offer a really clear definition and scope of construction safety management, on the idea of application range of various sensor-based technologies mentioned within the previous literature, it can be narrowed down to six aspects to discuss in detail, including AFS, SRPP, ISM, SHM, ST&E and DOM. The relationship between sensor-based technologies' application range and construction safety management is shown in Figure 2. The main applications of sensor-based technology in construction safety management are presented in Table below.

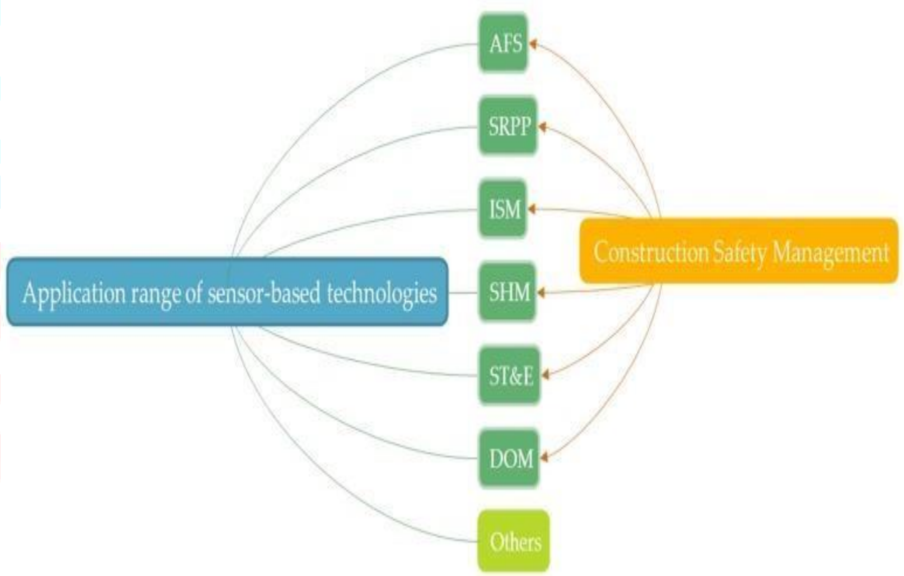


Figure 8: The relationship between sensor-based technology's application range and construction safety management

### 1. Accident Forewarning System

Under the background of construction, the security management for accidents usually adopts the approaches of "accident prevention" and "accident control". The former is for the accidents that haven't happened yet, while the latter is for the accidents that have happened or are happening immediately. Based on the preventive theory, "accident prevention" aims at discovering and eliminating the potential factors which will cause accidents. Compared with "accident control", "accident prevention" is clearly simpler and economical since the loss is irreversible when accidents have happened. On the idea of the "accident prevention" idea, utilizing accident forewarning system may be proper thanks to affect the potential factors which will cause construction accidents. It hold as an early warning system capable of complete and continuous detecting, judging and identifying unsafe behavior of personnel and machinery, and taking necessary actions like sending alerts to construction workers or managers. In other words, it provides support for the prediction and prevention within the accident prophase as an entire.
Before applying an accident forewarning system, few preliminary works must be done to supplement and improve the "accident prevention" idea. Soungho and Tomohiro collected and sorted the accident records of heavy equipment (e.g., excavators and cranes) on construction sites so as to seek out the explanations for accidents. This provided a foundation in fixing an anti-collision system for heavy equipment supported RFID and clarified the key elements within the system. Similarly, someone proposed solutions to stop tower crane collision accidents from developing an automatic planning tool supported sensing and simulation and numerical simulation, respectively.
In the accident forewarning system (AFS), the main research work focuses on three aspects: early warning index, early warning statistical method and the system applicability. With the event of early warning management theory, AFS

supported sensor-based technology has made a signification breakthrough. For example, suggests potential factors effecting construction safety through the applications of data technology in AFS. Studied the applications of 3S (GIS, GPS and RS) technology, RFID and knowledge technology in construction safety management, which may be extended to style the AFS. Furthermore, Wu and Grishma acknowledged that the WSN supported RFID, Zigbee and other location sensor technologies had been utilized in automatic identification and prevention of construction accidents. As for machinery equipment collisions, Zhong adopted specific sensors to watch the operation state of tower cranes. The collected data was transmitted to a foreign monitoring platform through wireless network supported Zigbee. The anti-collision algorithm was run within the terminal located in driver's operation room to make sure the security of crane tower during the entire construction. Aiming at reducing injuries in machinery accidents, researchers have tried to explore the answer from the twin perspectives of machinery equipment and workers, respectively. Ray and Teizer devised a system that might identify a driver's vision blind areas supported things of his or her head. The system then alerted the driving force to enhance concentration and take necessary actions to stop accidents caused by blocked sight. In order to supply real-time safety assistance to crane operators and to mitigate human errors during lifting operations, Fang developed a framework for real-time pro-active safety assistance for mobile crane lifting operations. The critical motions of crane parts were captured by a sensor system and therefore the lift site conditions were modeled supported point cloud data. Field tests proved the validity of the system in making timely decisions to mitigate the danger. Park defined the development machinery's workplace as dangerous zones. When workers were too on the brink of these areas, a designed system would send alerts to workers automatically. The field experiments tested the system performance supported RFID, Bluetooth and magnetic signals, respectively. Applying many sensors, ultrasound and infrared, Lee developed and deployed mobile sensing devices in some dangerous zones in construction site, workers would be alerted by broadcasting or text messages once they came on the brink of the preset areas. Because of the massive occurrence of accidents involving falls from high elevations and their devastating consequence, some researchers are dedicated to promoting the forewarning system for these accidents. Carbonari classified areas which will have accidents arising from falling objects. The workers' real-time location was obtained by UWB location technology, supported which the managers were ready to determine whether the workers were in dangerous zones. If so, alerts would be sent to workers to remain far away from dangerous areas or concentrate to falling objects. The high frequency of false alarms has been identified as a serious limitation of prevalent methods for preventing struck-by hazards

## 2. Safety Route Prediction and Planning

### 2.1. Route Prediction and Planning for Machinery Equipment

Zhang et al proposed a location processing method supported UWB to help crane drivers. The labels at key positions of Grus were wont to predict the crane's route and trajectory so on improve driver's context awareness. Its efficiency was verified by tests in an outside environment. Yang et al used 2D and 3D pose tracking algorithms to trace the trajectory of crane's arm to predict the operation state of Grus. The field test showed that the crane's working condition might be identified correctly.

### 2.2. Route Prediction and Planning for Workers

With the route planning algorithm, the probability grids of workers' location were obtained, supported which the optimal route for workers on construction sites was proposed. Zhu et al obtained location information of workers and equipment by using multiple cameras at a construction site. The trajectories of workers and equipment were analyzed by a Kalman filter, which may predict their next locations too. The experiments verified its prediction accuracy.

## 3. Integrated Safety Management

The content of integrated safety management includes two parts: quality inspection for construction materials and resources and management for workers' health and safety.

### 3.1 Quality Inspection for Construction Material and Resources

The quality of construction materials and resources has an impact on construction safety in an indirect way. On one hand, supported the opinions of housing industry experts, the hidden troubles caused by quality defects and cheating on labor and materials may cause serious safety accidents within the operation and maintenance stages; on the opposite hand, quality defects can cause quality issues like rework and repair, resulting in demolition, schedule pressure, extra working time and unstable work processes, which can all increase the danger of safety incidents. To verify this hypothesis, on the idea of empirical data collected from 32 building construction projects, ranging in scope from \$50,000 to \$300 million dollars, Wanberg tried to hunt out out the connection between quality performance and construction safety with empirical inquiry. Recordable injury rates were used as response variables. The rectilinear regression among predictor and response variables showed that the primary aid rate is positively correlated to number of defects ($r^2 = 0.548$; p-value = 0.009) and the OSHA recordable injury rate is positively correlated to transform ($r^2 = 0.968$; p-value = 0.032). In general, a project with a poor quality performance features a higher likelihood of injuries, which features a negative impact on construction safety. Thus linking construction safety to quality fabric and resource provides a nice path to encourage safety improvements.

Establishing a top quality inspection and management system of construction materials and resources may be thanks to fulfill total quality management (TQM), which may cause simultaneous improvement of both safety and quality. As a big a part of the above system, the accurate real-time location of construction materials and resources are often acquired by sensor-based technology. Along with other vital information including material and resource inspection reports, certifications, time of arrival and time of departure, the system can't only provide information required for management work automatically but also significantly save time with costs. Compared with traditional management, it solves the disordered, complicated and inefficient situation in quality inspection and management, which helps to scale back the danger of quality defection at the start. At present, scholars are exploring the likelihood of applying different sensor-based technologies to quality inspection and management system of construction material and resource. The RFID technology has attracted much interest thanks to its technological maturity and locating ability in indoor environment. Combined with other sensor-based technologies, the systems are often further applied to quality inspection. Chen developed an automatic positioning system for precast concrete components supported RFID and GPS for the aim of reducing incorrect installation caused by components' misalignment. Wang the tests showed that the system could improve the timeliness of the standard inspection work, reduce operation costs and increase customer satisfaction. Similarly, combined RFID with UWB to understand effective management for busy construction sites. It is seen that the system could simplify management processes of large-scale construction projects and ultrasound and vision-based sensing were also applied within standard inspection and management work for construction material with resource.

**3.2 Management for Workers' Health and Safety**

Over-exposure to heat and high humidity working environments is that the direct explanation for some occupational diseases, which can directly affect the private mental state of workers and therefore the behavioral effects of the work [61], increasing the danger of construction safety accidents. Therefore, the management for workers' health and safety may be a crucial a part of construction safety management. Similar to construction material and resources, various sensor-based technologies provide a replacement platform for worker health and safety management. It proposed a surveillance system (RFEMS) based on the radio frequency identification tags to track-identify workers on construction sites. It was energy-saving and will constantly work for quite 124 h as proved by field experiments. The system could recognize workers' activity patterns and laid a foundation of worker health-safety management. The rescue and safety management of workers in emergency cases might be realized visually through this technique.

**3.3 Structural Health Monitoring**

The infrastructure quality and security issue is said to the livelihood of individuals, and associated with social stability and healthy development of the economy. The consequences of infrastructure's damage are potentially catastrophic. Monitoring the related indexes like temperature, deformation, stress and displacement may be proper thanks to acquire health and safety condition of the infrastructure in real time. Hence, the structural health monitoring is a crucial a part of construction safety management. Sensors and WSN play a crucial role in structural health monitoring and are widely applied to safety management of construction sites. For example, temperature sensors embedded in concrete can record the concrete hardening process in an early phase, which has been wont to evaluate the standard, compressive strength and flatness of concrete [64]; glass fiber sensors embedded in concrete are applied to watch the strain and cracks of structures. Recently WSN has been widely utilized in structural health monitoring of bridges, dams and other important infrastructures concerning human life. For example, developed a WSN for structural health monitoring of China National Stadium (Bird's Nest). The network is composed of 295 sensors, measuring stress, displacement, acceleration, wind speed and temperature. The data collection lasted for quite a year and therefore the results were satisfactory. Furthermore, designed a WSN for structural health monitoring. Similarly, the WSN is utilized in structural health monitoring for new headquarter of Shenzhen stock exchange (NHSSE). As one of the most important cantilever structures within the world, NHSSE's strain and deflection data are vital for structural health. 224 sensors were installed to live the strain, deflection and overall dynamic responses. The WSN is low-cost and straightforward to deploy and maintain. Along with various sensors, it's versatile enough to satisfy different requirements. Various magnitudes of interest like acceleration, displacement, stress, temperature, etc., are often acquired simultaneously during a real-time manner. In addition, the system could provide an efficient way for data management and thus save time and labor.

**3.4 Safety Training and Education**

Safety training and education (STE) for worker have positive effect in improving safety management with reducing the occurrence of accident. More concretely, based on the experience of construction industry expert, the benefits of ST&E for workers are as given as: (a) promote safety consciousness, align the interests of workers with security purposes; (b) adjust production and conduct safety operation positively; (c) obey safety regulations and policies consciously; (d) actively check and eliminate dangers; (e) identify hazards and dangerous zones in advance, master effective response measures to safety. Compared with traditional safety training and education, the sensor-based technology provides a completely unique approach to implement it. Tao et al. [77] built a framework supported real-time positioning data collected by sensor-based technologies. Three case studies showed about framework performed well in data recording and visualization. It could simulate construction site, outdoor construction environment and workers' training environment, which provides a good platform for worker' ST&E. By connecting remote and off-site supervision, it offers a good opportunity for workers' off-site ST&E.

**3.5 Highly Dangerous Operations Management**

The construction of infrastructures like tunnels and mines may be a complicated process thanks to the unstable and unpredictable construction environment. Accurate positioning and real-time tracking of worker not only serve for real-time safety monitoring of dangerous area, but also provide a reliable means to rescue trapped people timely in accident. Lin et al. [79] developed a real-time tunnel location-based services (LBS) system (LBS) supported a WLAN. Taking advantage of fingerprint coding algorithms and a man-made neural network, it could estimate workers' positions supported signal intensity with an accuracy of 3–5 m shown within the field experiments. It's been successfully applied to safety management of the world's second largest hydropower project. Yuan et al. [80] used WLAN to create a high speed heterogeneous network which was ready to adapt to a spread of harsh underground environment with low energy consumption, long operating life and high positioning accuracy. As an enormous mining country, China has been embarrassed by the frequent mining accidents thanks to its lagging technology and weak security awareness. In recent years, alongside the event of technology and therefore the promotion of safety management, an excellent improvement went on in China in mining safety. An outsized number of methods supported location sensors are proposed for real-time underground positioning in coal mines. Some studies are mature and have resulted within the establishment of practical systems. For instance, RFID-based underground positioning has been verified by experiments and practice. The system has been promoted during a wide selection. Safety management of highly dangerous operations inspires for construction safety management. The advancements in construction techniques and management have greatly reduced the speed of severe construction accidents; however, monitoring the position of workers in dangerous workplaces isn't a waste of resources. In case of abnormal situation or accident, the managers may acquire timely and vital information and can take effective measures to scale back the impact of accident. On-site rescue operations will save time and avoid some accidents.

## VIII Types of Safety Performance Measurement

There are two types of safety indicators widely utilized named as “leading” and “lagging” (output measurement, or post-accident measurement) safety indicators. Leading indicator is preferred in both industry as well as academia.

### 1. Lagging Indicators

The development industry has measured safety performance supported lagging indicators like total recordable injury rate (TRIR) and death rate (Hinze et al., 2013). According to Lingered et al. (2013), the rationales for the recognition of those methods are that they are

- Easy to collect
- Understood easily
- Comparable with each other
- Used in benchmarking
- Useful in the identification of trends

Lagging indicators record “after the fact” failures. Since the probabilities of occurrence of any recordable injuries or fatalities are low, they might not be ready to identify any changes within the safety management system. Lagging indicators measure the absence of safety instead of the presence of safety. Sometimes injury rates are associated with other things like reward systems, bonuses, and manager performance appraisals. These rewards can cause perverse incentives causing employees to underreport. It should be noted that some indicators like near miss reports have been categorized as leading indicator and lagging indicator. Someone has have investigated this problem and came up with characteristics for each near miss report. They stated that if mishap report is being implemented in firms as a recordable, then it's considered a lagging indicator. If it's being implemented as a proactive indicator, then it should be categorized as a number one indicator. Prevailing lagging indicators that are getting used during a sort of industries are explained briefly below. Calculations of every indicator alongside an example for every calculation also are provided for better clarification.

### 2. Leading Indictors

There is a spread of definitions for leading indicators. These are gathered from researchers and organizations and reported. The use of leading indicators has increased recently supported the amount of organizations that have implemented also as increased research with the main target on leading indicators. There are plenty of advantages for using safety leading indicators. One of the benefits is that leading indicators provide a measurement on how well the organization is performing in terms of safety. It could give proper feedback to safety management for improvement before some accidents happens. Mostly, leading indicators are built supported the literature and studies of the direct explanation for accidents. As an example, operational errors might be a number one metric and researchers established measurement for that indicator.

## IX Directions for Future Work

Several directions for future research are identified:

(1) Integrated sensor-based technologies Single sensor-based technology cannot satisfy the ever-increasing difficult requirements introduced by the requirements of construction safety management. For instance, combining GPS and other wireless locating techniques usually yields better positioning results. The previous is employed to locate outdoor people and machinery equipment, while the latter is applied to amass accurate positioning data of construction materials, resources and other people in complex indoor environments. Meanwhile, multiple sensor-based technologies can share the responsibility for enormous information collection, reduce the failure rate of the entire system and improve the general stability and suppleness.

(2) Expansion in information dimensionality and data utilization At this stage, the appliance of sensor-based technology is subject to strong restrictions so the collected information of construction environment has lower dimensionality. for instance, the first data covers either the dimension of your time or dimension of space, but the manager must make decisions supported data providing both temporal and spatial information; the first data only provides a worker’s physical position, but the manager needs the worker’s physiological information to see whether he or she is safe. The collected information typically covers only some dimensions, which ends up in the awkward situation that safety management cannot be reliably conducted thanks to incomplete information. At the identical time, the capacity of processing the collected information isn't satisfying. Only a tiny low a part of data will be identified and utilized, remaining the foremost

part ignored directly. a way to expand information dimension and increase the information utilization is of critical importance within the application of sensor-based technology in construction safety management.

(3) Exploration in various fields
The application of sensor-based technology in construction safety management covers the entire process of construction projects, including planning, design, construction and operation. The systems, frameworks, models and algorithms proposed haven't been fully tested in real construction environments; therefore, the particular performance is unknown to some extent. Only some studies have investigated the cost-benefit of sensor-based technology, thus it's not validated to push its application in construction safety management. In general, actively seeking the exploitation and exploration in various fields of sensor-based technology application is one in every of the present development trends in construction safety management.

(4) Hardware cost control and processing simplification
It's vital to manage hardware costs within an affordable level and simplify processing of software. One direct consequence of cost control is that the lack of accuracy in measurements. Though, to a particular extent, it is compensated by using more complex algorithms, it's generally impractical to complete huge computation tasks at construction sites, which can inevitably increase the hardware costs also. Taking the case of identification of workers' unsafe behavior, a cheap and mature technique with simple layout (e.g., vision-based sensing) usually finishes up in a complicated subsequence. Specifically, the contour extraction, noise reduction and posture recognition relies on algorithms and models with high complexity or huge computation burdens, which aren't practical to perform at construction sites. On the opposite hand, the one-sided pursuit of simplification in processing usually requires highly complex sensors and data transmission systems. These devices are expensive and harsh to put in and maintain. Therefore, seeking the balance between hardware feasibility and software simplicity is of great importance within the healthy development of sensor-based technology in construction safety management.

(5) Smartphone-based interactive safety management platforms
Smartphone are an integrated platform containing multiple sensors. In recent years, smart phones have remained affordable because of their substantial popularity and price advantage, as a result of large-scale production. Smart phones have the potential to become an information management platform by virtue of their processing ability and overall performance. A more desirable feature is that smart phones are open source systems with a contemporary software development environment, which is useful in information collection and processing. Nowadays, some researchers have shifted their focus of research to the appliance of smart phones and further exploited their features to make interactive platforms for construction safety management. With the assistance of a synthetic neural network algorithm, the explanation for energy release (slip or trip) decided. Within the aspect of classification and prevention of high altitude falling accidents in building construction, Kim designed a real-time position and risk automatic identification system supported smart phones and BIM technology. Their field experiments showed that the system could enhance the flexibility of environment monitoring on construction sites and had a possible in identification of high altitude falling accidents. Dzeng utilized smart phones to detect and identify the signs of high altitude falling accidents. Their tests showed that an acceleration-based algorithm could detect the signs of high altitude falling accidents effectively and accurately and it might not suffer from interference by construction activities.

## X Site survey

We have conducted a site survey at a construction site near Mumbai, in which we have asked a set of questions to workers and contractors and their responses are given below.

| Sr. No. | Questions | Workers Feedback | | | | |
|---|---|---|---|---|---|---|
| | | **Very Good** | **Good** | **Satisfactory** | **Poor** | **Very Poor** |
| **1.** | First aid center | | ✓ | | | |
| **2.** | First aid medicines and accessories | | ✓ | | | |
| **3.** | Availability of doctors/nurses | | | ✓ | | |
| **4.** | Treatment provided by doctors/nurses | | | ✓ | | |
| **5.** | Sanitization facilities | | ✓ | | | |
| **6.** | Storage section | | ✓ | | | |
| **7.** | Safety gears provided | | ✓ | | | |
| **8.** | Scrap dump areas | | | ✓ | | |
| **9.** | Arrangement of scrap and waste disposal | | | ✓ | | |
| **10.** | Quality of PPE kit provided | | ✓ | | | |
| **11.** | Falling object protections | | ✓ | | | |
| **12.** | Ambulance availability | | | | ✓ | |
| **13.** | Use of advance technology | ✓ | | | | |
| **14.** | Quality control | ✓ | | | | |
| **15.** | Behavior of higher authorities | | | ✓ | | |
| **16.** | Cleanliness of the site | | | ✓ | | |
| **17.** | Toilet facility | | | | ✓ | |
| **18.** | Overall site environment | | ✓ | | | |

**Worker's feedback**

| Sr. No. | Questions | Contractor's answers | |
|---|---|---|---|
| | | Yes | No |
| **1.** | Are safety gears provided on site? | ✓ | |
| **2.** | Are fire extinguishers available on site in case of emergency? | ✓ | |
| **3.** | Are safety ambulances available on site? | ✓ | |
| **4.** | Is proper sanitization available during pandemic? | ✓ | |
| **5.** | Is PPE provided to everyone? | ✓ | |
| **6.** | Are doctors/nurses available at the site? | ✓ | |
| **7.** | Are safety gears provided on site? | ✓ | |
| **8.** | Are on-site oxygen cylinders available in case of emergency? | | ✓ |
| **9.** | Are precautionary measures take care of to prevent fall and slip? | ✓ | |
| **10.** | Is proper training given to workers before joining? | ✓ | |
| **11.** | Are there any children working on-site? | | ✓ |
| **12.** | Is toilet facility provided on-site? | ✓ | |
| **13.** | Is there protection provided to prevent falling object from above? | ✓ | |
| **14.** | If any worker gets injured then does he/she provided some amount of money for treatment? | | ✓ |

**Contractor's response**

## XI Conclusions

This paper has provided a proper comprehensive and systematic review of sensor-based technology applied in construction safety management from 2005 to 2017. So as to present an objective evaluation of the present research status and future trends, a two-stage literature selection method was applied during this research. Taking Web of Science as a primary source and Engineering Index as a supplement, the research identified 93 papers within the preset topics and formed a database. The year profile of publications, application trends of sensor-based technology and distribution of research topics were statistically analyzed. Furthermore, the trends of the research topics and application potential were discussed within the analysis.

Sensor-based technology contains of location sensor-based technology, wireless sensor network and vision-based sensing. The paper summarized the positioning accuracy of locating sensor-based technology including GPS, RFID, WLAN, UWB, Zigbee and ultrasound, and gave a short introduction to vision-based sensing and wireless sensor network. Meanwhile, the applying status of sensor-based technology within the above fields was introduced objectively and systematically. Supported the previous achievements, the paper identified the research gaps, acknowledged future research directions and showed the prospects of future development.

In general, single sensor-based technology isn't directly applicable in construction safety management. Only the combination of multiple techniques is capable of meeting the ever-increasing requirements. Since the hardware and software are the most essential parts of sensor-based technology, a balanced realization will achieve faster and better progress of sensor-based technology in construction safety management. As an integrated platform of multiple sensor-based technologies, in recent years, the worth of smart phones became attractive due to their substantial popularity and price advantages resulting from large-scale production. Additionally, because of the info processing ability and overall performance of smart phones, they need the potential to become an information management platform supported an open source system, which is useful in information collection and processing. Generally, smart phones take both the hardware costs and also the software compatibility into consideration and balance their relation in their evolution. Beyond that, compared with other sensor-based technologies, smart phones have some significant advantages, making them an optimal choice for both effective data acquisition solutions and portable processing platforms. Considering the environment of construction sites and therefore the information requirements of safety management, within the foreseeable future, smart phones will have an increasing role to play in interactive construction safety management. Lastly, there's still an extended thanks to choose the event of sensor-based technology construction safety management from theoretical research to exercise. Nevertheless, without a doubt, this field of application has an incredible potential and a bright future.

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