IMPLEMENTING SMART SAFETY IN A MEGAPROJECT

By Steven Abaray and Hasan M. Al Mubarak

Smart safety is the use of technology to provide qualitative and quantitative enhancements to construction safety with the goal of reducing incidents and injuries through prevention. The goal of smart safety is not to replace but instead enhance the effectiveness and efficiency of industry-proven safety practices.

The smart safety system described in this article is an adaptation of traditional safety methods, utilizing the same guiding principles combined with advanced technology to improve on the safety management process. Smart safety is a force multiplier. Even with robust training programs, site supervision and site surveillance, incidents can happen for myriad reasons. While every incident is preventable, the likelihood of prevention can be enhanced with increased monitoring and ability to recognize an unsafe situation before it escalates. While this can be accomplished without smart safety, it is very challenging. Smart safety does not replace these valuable safety personnel, but rather helps them quickly identify safety concerns such as hazardous situations, unsafe conditions and inadequate PPE in large areas.

Smart safety is a commitment to enhancing construction safety that not all companies are prepared to make. Barriers include the challenges of implementing the technology on a construction site as well as high initial cost and continuing maintenance costs when compared to traditional safety management systems. Smart safety is also something that should be adaptive; as technology continues to improve, companies that are committed to smart safety must remain active and engaged. One leading international energy company committed to smart safety has included it in the contracts for new megaprojects so that it cannot be regarded as optional.

SMART SAFETY IN ACTION

- **Start small, scale smart.** Implement individual smart safety components such as AI cameras or smart helmets early, before full system rollout, to gain benefits and refine operations.
- **Empower the control center.** Ensure that the on-site safety control center is well staffed and operators are fully trained to quickly act on alerts and manage integrated technologies.
- **Integrate, do not isolate.** Plan for system compatibility early. Coordinate software, data and cybersecurity needs so all smart safety technologies work together effectively.
- **Use data proactively**. Generate daily and trend-based reports from the smart safety system to guide training, supervision and resource adjustments in real time.
- **Plan for evolution.** Regularly evaluate emerging technologies (e.g., AI camera upgrades, drones, digital passports) to enhance monitoring and adapt to project growth.
- **Leverage productivity insights.** Use smart safety data not only for risk prevention but also to track workforce efficiency, equipment use and progress metrics for better project management.

Smart Safety Technologies

Workforce Tracking With Smart Helmets

Workforce tracking is crucial for large projects, especially when the project includes many workers or when the work area is spread out. With a large construction site or multiple work locations, it might not be apparent if the appropriate number of safety personnel are present or support facilities (e.g., rest areas, toilets, medical) are in the correct locations. Smart helmets are a wearable device solution that provide real-time locations for all construction personnel.

While wearable devices are not new to the construction industry, integrating the device into safety helmets, which are mandatory PPE for all site personnel, ensures that the device is always with the worker and cannot be misplaced or forgotten (Parsi, 2018). Each worker, regardless of company affiliation, is provided with a smart helmet specific to them that includes their name, company affiliation and job title or craft. Personnel locations are displayed on screens so that safety officers can see which personnel are in an area at any given time and adjust support facilities or increase the number of safety personnel in the area as needed.

Smart helmets also include features such as built-in sensors and a panic (SOS) button (see Photo 1). The sensors detect whether the helmet is being worn as well as whether the helmet has experienced a significant impact or fall. The panic button immediately alerts the smart safety system when pressed. Impact and SOS alerts display on the system operator's screen, and the safety officer can immediately mobilize assistance to that location.

Cameras With AI Processing

Advancement in camera technology has led to the development of AI cameras capable of scanning large areas with zooming and high-resolution capabilities. AI is being integrated into project management at many levels today and is also now used to enhance safety (Nieto-Rodriguez & Vargas, 2023). Without the need for a person monitoring a screen, these cameras identify unsafe acts such as personnel not wearing correct PPE, and unsafe conditions such as a worker standing within a certain radius of heavy equipment or too close to a load suspended from a crane.

Whenever AI cameras identify an unsafe act or condition, the smart safety system alerts a system operator and creates a photo or video of the event. The operator then decides whether it is truly an unsafe act or condition and further escalates by notifying either the safety personnel or construction supervision in the area. The system operator is key, as false alarms may occur due to certain camera angles. However, smart cameras can cover an entire construction site when placed strategically. This system can provide more surveillance and quicker response than either patrolling safety personnel or cameras without AI that require active monitoring by multiple personnel. The AI cameras work both day and night and have no

downtime other than routine maintenance. In addition, records of safety violations captured by AI cameras are saved for training purposes, incident investigation and disciplinary action if warranted.

Vehicle & Equipment Tracking

The use of global positioning system (GPS) tracking of vehicles is not novel; however, the smart safety system incorporates detailed heavy equipment or vehicle tracking on the construction site. All construction vehicles are monitored regardless of company affiliation, including heavy equipment. Monitored vehicles are shown on a system operator's screen and are individually programmed to show the type of vehicle and company affiliation. Smart safety automatic vehicle locating systems track speed, indicate whether the vehicle or heavy equipment is working or idle, and monitor emissions, and they can show the historical movements for any period of time. The vehicle maintenance schedule and maintenance record can be programmed into the smart safety system to enable maintenance alerts, potentially facilitating preventive maintenance planning and avoiding unplanned downtime from equipment failure. Smart safety system operators can also watch overall traffic patterns in real time to identify congested areas with too many people and vehicles in close proximity and alert site safety personnel to evaluate and implement additional traffic control measures.

Environmental Monitoring

Weather causes severe disruptions to outdoor construction activities, especially in parts of the world with extreme heat or cold conditions. Company safety programs often follow prescriptive, tiered mitigation plans for these conditions, but the changes in weather conditions may not be captured quickly. For example, a company might have one protocol for mandatory rest periods and hydration requirements for an ambient temperature greater than 90 °F and another protocol for when the temperature climbs to greater than 100 °F. However, if personnel are not aware that the temperature has risen to a higher threshold, then the appropriate mitigation actions are delayed, potentially placing workers at risk. Another example is the effect of wind speed on construction activities such as the use of manlifts and crane lifting operations. Companies often have a hard wind speed limit that suspends the use of manlifts and crane lifting operations when exceeded. The safety implications of lifting in high wind speeds can be catastrophic.

To better and more quickly adapt to changes in weather, an on-site weather station is integrated into the smart safety system. This weather station is equipped with several different real-time environmental monitoring capabilities such as carbon dioxide, temperature, relative humidity, wind direction and wind speed and enables supervisors to adjust rest breaks or preemptively suspend crane lifts.

Lightning is another environmental threat to outdoor construction work. In general, when a lightning strike is visible, it is already close enough to be a threat, and it takes time to move workers to safety on large project sites. To address this safety risk, a lightning detection system is integrated into the smart safety system. The lightning detection system can be configured to detect lightning at certain distances such as 10 or 15 km even when it cannot be visibly observed by anyone at the construction site. Following a detection, a supervisor can mobilize workers to shelter before the lighting arrives as well as sound the all clear once the threat has passed.

Digital Permit-to-Work

On any given day on a megaproject, hot or cold work and confined space entry may take place at multiple locations throughout the worksite. Given the risks associated with each type of work, many companies have specific work permits that detail the work to be done, the hazards associated with the work and mitigation required for those hazards. However, keeping track of these work permits and the associated locations for the work can be challenging on large sites with many active work permits every day.

One way to see all work permits and their associated details at any given time is to integrate the work permits into the smart safety system with digital permit-to-work. The permit type and specific details of the work are shown on the same screen that displays workforce tracking and heavy equipment locations. The smart safety system retains records of all work permits for the project duration and shows whether a work permit is active or suspended as well as contact information for the people associated with the permit.

Photo 1: Smart helmets include valuable features such as built-in sensors and a panic (SOS) button.

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Supervisors can verify that all assigned personnel and heavy equipment are at the work location at any time.

With multiple companies and different types of work in the same area, different work crews might not be aware of everything happening around them or the associated dangers. By utilizing digital work permits, simultaneous operations areas of risk can quickly be identified and safety officers can take appropriate steps to alert the associated personnel or even suspend work that cannot be completed safely with other personnel in the same area.

Digital Passport

It is very common, especially with megaprojects, to have multiple contractors and subcontractors working on the project at the same time, each with their own scope. However, all construction personnel are required to follow the client's governing safety rules and receive certain minimum levels of safety training depending on their craft. Specialized crafts are required to have specialized training in addition to jobsite safety training. Keeping track of safety and specialized training for all personnel, across multiple companies, is tedious. This is compounded by the requirement for all trainings to be refreshed or renewed at different time intervals as well as the day-to-day

addition of personnel and equipment to the project.

The smart safety solution to training record management is the digital passport, a digital record for each person that shows the training required for the position, the completed training, and when the refresher or renewal courses are required. To mitigate any potential negative impact to work productivity, the system generates an alert whenever a worker has a training deficiency or required upcoming training. For audit purposes, each worker is issued a scannable near-field communication tag in the smart helmet so that any auditor can simply scan and verify that the worker is performing the task they are authorized and trained to perform. This could also be accomplished with a QR code sticker for each individual.

Smart Safety Organization

Project Management Team

The client project management team (PMT) for a megaproject is typically composed of the project manager, senior project engineers, discipline project engineers, field compliance (safety) coordinators, procurement representatives and quality inspectors who, in addition to safety performance, must also focus on aspects of managing a project such as engineering, procurement, and construction schedules and costs. The smart safety system does not replace the need for management site visits and safety audits, but it does allow the PMT to convert a large amount of construction safety data into focused and actionable real-time summaries. The PMT can see trends of safety observations which, if using traditional safety management systems, would be lagging the actual performance due to the time required to collect and analyze data manually.

Safety Control Center

The brain of the smart safety system is the safety control center. It is the building located at the jobsite that contains all the operators for the smart safety system as well as the technology and workstations the operators need to perform their job satisfactorily (see Photo 2). For smart safety to succeed, safety managers must ensure that the safety control center is adequately staffed and that personnel are trained to use all subsystem technologies and empowered to act quickly.

Photo 2: The safety control center, located at the jobsite, contains all the operators for the smart safety system as well as the technology and workstations operators need to perform their job.

Implementation & Operation

Scaling Up & Overcoming Challenges

When implementing a smart safety system for a megaproject, it is important to plan for the full system requirement and the maximum project workforce and equipment, but that does not mean the entire system must be completely ready on the first day. Especially for lump-sum turnkey contracts where the contractor may be responsible for the cost of the smart safety system, implementing even one part of the system at the earliest possible stage is better than waiting until the entire system is ready to go live. Each subcomponent of the system has value on its own and can enhance the project's safety performance. A thorough plan for the full smart safety system must be developed as part of the project safety management plan but understood by the PMT that scaling up should be expected.

During the processes of initial implementation, scaling up and operation, unforeseen challenges arise that require attention from the PMT, the system vendor and system operators. For example, an AI camera view may become obstructed following the construction of a wall or building structure, requiring the camera to be relocated or an additional camera to be placed. These types of changes should be expected, and there should be service agreements in place to ensure that the changes are executed in a timely manner to maximize the system's effectiveness.

The smart safety system is a living system that requires maintenance. Even when a system is running at its full strength and all technologies are functioning as desired, events such as failure of a camera, communications hardware, screen or weather station sensor could impact the system. There should be contingency plans in place that are acted upon quickly when necessary. If contingency plans do not yield the desired results, then it is important to quickly incorporate lessons learned and execute new plans.

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Systems Compatibility

Systems compatibility can be a challenge when it comes

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to smart safety system implementation and operation. Because of the various technologies that make up the system, it can be challenging for the integrator when it comes to software licenses, interprogram communication, software updates, intellectual property and cybersecurity considerations. There may be some desired smart safety technologies that are not feasible to integrate into the system. An integrated system that works and can be utilized by the operators is better than a superior technology that cannot be effectively integrated. It is very important, especially in the early planning phase, to fully understand the integration requirements for all technologies and the ability to scale and adapt to growth and operation needs of the system.

Daily Reports

A smart safety system that works in a vacuum or cannot share actionable summaries is ineffective because smart safety system outputs should be utilized to determine focus areas for safety such as specific needs for supervision and training, and positive and negative trends. When it comes to a construction site that is evolving daily, the smart safety system and operators must be able to generate daily reports to keep pace. The daily report content should be determined initially and kept simple so that actions can be taken without becoming overwhelming. Potential daily report content could include significant events, alerts, workforce updates, vehicles and weather.

Expansion With Project Need

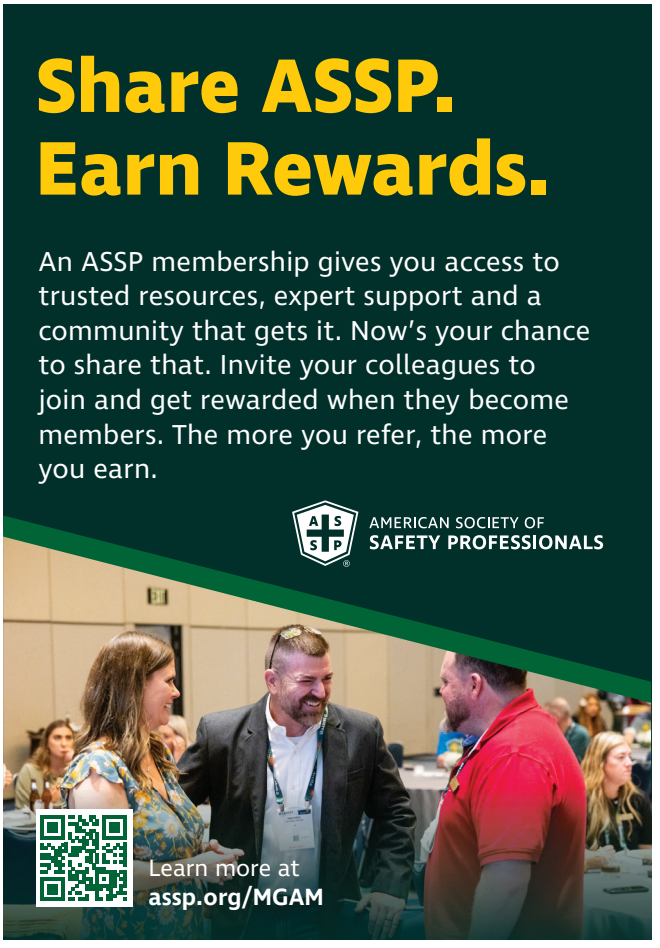
There are two types of project expansion that affect the smart safety system: increase in personnel or equipment and increase in physical project area. Every megaproject has worker and equipment histograms that best predict the peak numbers and rate of change. The smart safety system plan must take these histograms into account, especially when looking at system capacity and communication capabilities.

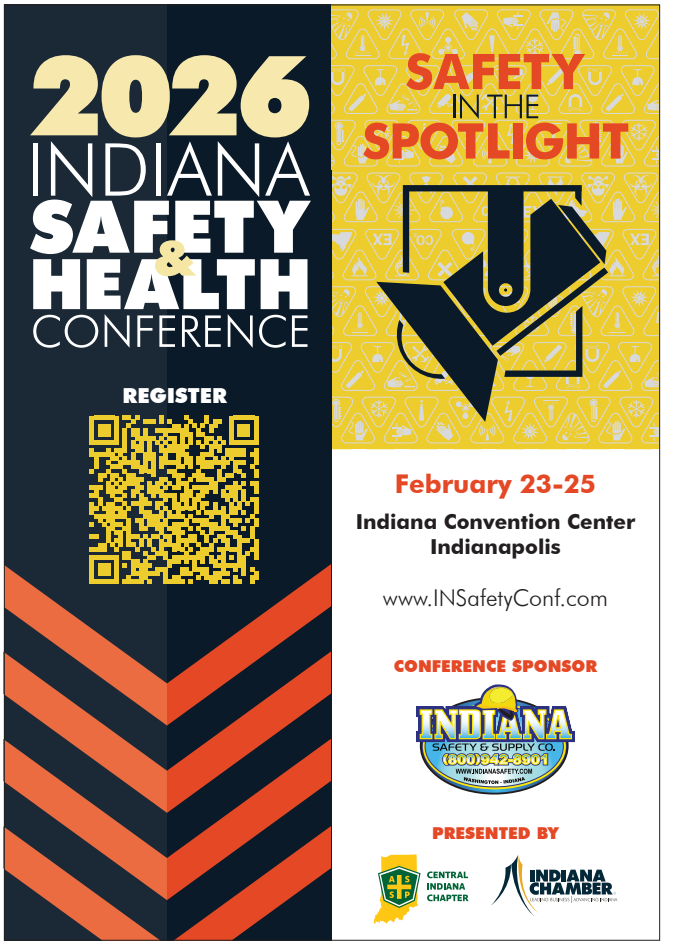
Because several of the smart safety system technologies involve monitoring the construction area, any changes to this area must also be updated in the smart safety system. This could result in additional cameras, additional smart helmet communication hardware or additional weather stations. Additional work areas also impact the plot plans used to show locations for workers, vehicles and heavy equipment, and work permit tasks. If those plot plans are not updated, blind spots will result.

Evolution of Systems

As technology continues to evolve at a fast pace, the smart safety system should be evaluated regularly to see whether new or improved technologies can be used to enhance the existing system. Some potential opportunities include:

- **Upgraded AI cameras.** Upgraded AI cameras could include enhanced range and enhanced low light vision.
- **Smart area four-gas monitors.** Integrating portable area four-gas monitors into the smart safety system and associating them with digital work permits is especially effective for confined spaces.





- **Automated work permit vicinity tracking.** An automatic alert can be sent when the required personnel are not in the area of a work permit such as work permit receiver, safety team, and special roles such as fire watcher and standby person.
- **Surveillance drones.** Drones can offer surveillance flexibility on a construction site, with the same capabilities as a fixed camera but not anchored in one place. Integrating drone cameras into the smart safety system, especially with AI capability, can provide increased monitoring of remote and extended areas such as linear construction projects. However, this may require a drone operator, and flight paths would need to be carefully controlled to ensure that drone failure does not harm people or equipment.
- **Tools and utilities tracking.** Expand the automatic vehicle locating system to include utilities such as generators and welding machines to track utilization and ensure proper maintenance.
- **Body temperature scanners.** Recent world health events have made crowd body temperature scanning more prevalent than in years past. Implementing a body temperature scanning program within the smart safety system could identify individuals who are sick and should be quarantined for rest, which can help prevent the spread of disease. A body temperature scanning program could also help prevent heat- and cold-related illnesses.

Additional Benefits

Workforce, Equipment & Progress Metrics

While implementing a smart safety system on a megaproject, productivity metrics could be generated using the same smart safety technologies without any additional changes to the system or additional costs. While these productivity metrics were not part of the initial system goals, the ability to extract productivity trends and impacts was an unexpected benefit.

One particular benefit was the ability to see the total workforce on the site at any time and on any day. The name, company and job description of every worker is also stored in the system for historical use, and smart helmets indicate whether someone is actively working or idle. A system operator can generate a report per company, for example, showing whether workers arrive on time each day and how many hours are actively worked for each person, each day.

Similarly, the smart safety system vehicle and equipment tracking, combined with the digital work permit tool, allows the PMT to see the total number of vehicles and heavy equipment working on the project as well as the utilization for the various active work permits that require heavy equipment. The PMT is also able to examine further to see if the types of heavy equipment are appropriate and sufficient for the work being performed.

In addition to workforce and equipment analysis, AI cameras can be used to take dated time-lapse video and still photos to capture the actual progress for the entire project area. This allows the PMT to have a historical record of progress, which they can compare to the planned progress and analyze the best performers or areas for improvement.

Project Close-Out

The data captured by the smart safety system, especially in terms of total workforce, task-related work, equipment quantities, equipment types and actual task durations (possibly based on work permit validity) can be utilized at the project end to adjust benchmarking and estimating expectations for future comparable projects. Specific construction contractor or subcontractor performance can be segregated and used in company evaluation criteria to identify top performers who also have a commitment to safety.

Conclusion

Safety performance is a key factor in determining construction project success (Ashley et al., 1987). It can be tempting for companies who have excellent safety programs to continue the status quo. However, when it comes to combining safety management and technology, enhancement of even the best safety programs is possible with proper utilization of the smart safety systems described in this article.

When it comes to combining safety management and technology, enhancement of even the best safety programs is possible with proper utilization of smart safety systems.

Safety professionals are encouraged to embrace these new tools as a means to reduce overall risk and enhance their safety management programs based on specific needs. While the full complement of smart safety systems may not be beneficial in all situations, each subcomponent offers benefits and measurable results that can be easily presented to company management. In addition, the cost and ease of implementation will improve as technology continues to mature. Therefore, embracing smart safety technologies and building experience and familiarity with them should be a goal for safety professionals who are charged with safe execution of megaprojects. **PSJ**

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Steven Abaray, P.E., PMP, is a lead project engineer at Saudi Aramco. He holds a B.S. in Electrical Engineering from Texas A&M University, and he has worked for various energy companies for more than 19 years as a technical project engineer in multinational onshore and offshore major capital projects. Abaray is a professional member of ASSP's Gulf Coast Chapter.

Hasan M. Al Mubarak, PMP, is a senior project manager working on megaprojects at Saudi Aramco with more than 30 years' experience executing projects for refining, natural gas liquid recovery and gas treating facilities as well as pipelines. He holds a B.S. in Chemical Engineering from King Fahd University of Petroleum and Minerals in Saudi Arabia. Al Mubarak has received the Society of Petroleum Engineers Regional Award for Regional Projects, Facilities and Construction for the Africa Region and the Construction Award for the Middle East and North African Region.

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