Safety Science 98 (2017) 50–69

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Cloud-based safety information and communication system in infrastructure construction

Patrick X.W. Zou [a,*], Percy Lun [a,b], Dean Cipolla [b], Sherif Mohamed [c]

[a] Department of Civil and Construction Engineering and Centre for Sustainable Infrastructure, Swinburne University of Technology, Melbourne, Australia
[b] John Holland Group, Melbourne, Australia
[c] Griffith University, Gold Coast, Queensland, Australia

ARTICLE INFO

Article history:
Received 2 May 2016
Received in revised form 24 April 2017
Accepted 18 May 2017

Keywords:
Safety management
Safety information
Information technology
Cloud computing
Construction safety
Infrastructure project

ABSTRACT

This research aims to develop a cloud-based safety information and communication system for improving safety performance of infrastructure projects. To achieve this aim, firstly, current traditional paper-based construction safety management system and practice are described, together with a review of the potential application of cloud-based information technology in safety management. Secondly, a cloud-based safety information and communication system (named as MapSafe) was designed and developed by using a free-to-use online web server. The MapSafe system functions include Pre-Starting Safety Meeting Recording, Permit to Penetrate Request and Approval, Job Safety Analysis, and Safety Incident Reporting. The system was tested by using a road construction project and the results show it is a robust system that can be applied to improve safety. The key contribution of this research includes mapping the processes of safety information collection, analysis and approval, and pointing out the way for future application of cloud computing in construction safety management.

1. Introduction and research aim

Working in the construction industry is considered more risky than in many other industries. Statistical figures have suggested that both the rates of serious injury compensation claims and fatalities in construction have been consistently higher than their corresponding overall industrial average rate (Zou and Sunindijo, 2015). For example, according to Safe Work Australia's industry statistics reports (Safe Work, 2014a; Safe Work, 2014b), the Australian construction industry recorded 402 fatalities and 140,448 serious injury claims from 2003 to 2013. These records accounted for 14% and 10% respectively of the total national work-related fatalities and serious injury compensation claims, which were the third highest amongst all industries over the 10-year period. The need for better safety performance in the construction industry is eminent. Recent studies have reported that information technology (IT) innovations can be implemented in construction safety management through various applications including safety in design (Eastman et al., 2009; Hayne et al., 2014; Hu et al., 2008; Zhang and Hu, 2011), safety site planning (Azhar et al., 2012; Wang et al., 2014; Bansal, 2011; Naik et al., 2011; Cheng and Teizer, 2013; Guo et al., 2013; Huang et al., 2007; Lai and Kang, 2009; Li et al., 2003), safety risk management (Hartmann et al., 2012; Melzner et al., 2013; Zhang et al., 2015, 2013; Bansal and Pal, 2009; Baertlein et al., 2000; Talbot and Nichols, 1999; Hadikusumo and Rowlinson, 2004, 2002; Park and Kim, 2013), safety knowledge database (Park and Kim, 2013; Vossebeld and Hartmann, 2014), safety monitoring (Kimmance et al., 1999; Lee et al., 2009; Teizer et al., 2010; Yang et al., 2012; Han et al., 2009) and safety training (Park and Kim, 2013; Guo et al., 2012). A review conducted by Skibniewski (Skibniewski, 2014) on IT innovations in construction safety management from 2006 to 2014 reported that sensors and sensor-based systems for safety, robotics and manipulators for safety and information analysis and management technologies are the major topics among the studies. The Skibniewski (2014) review also showed that IT related topics consisting of building information modelling (BIM) for safety in design and safety risk management (Eastman et al., 2009; Hayne et al., 2014; Hu et al., 2008; Zhang and Hu, 2011; Azhar et al., 2012; Wang et al., 2014; Hartmann et al., 2012; Melzner et al., 2013; Zhang et al., 2015, 2013; Park and Kim, 2013; Vossebeld and Hartmann, 2014), sensor-based location tracking systems such as the Global Positioning System (GPS) for safety monitoring (Cheng and Teizer, 2013; Baertlein et al., 2000; Park and Kim, 2013; Lee et al., 2009; Teizer et al., 2010; Yang et al., 2012) and computer-aided design (CAD) were proven to be useful for creating better safety information management system. Other studies reported

* Corresponding author.
E-mail address: pwzou@swin.edu.au (P.X.W. Zou).

http://dx.doi.org/10.1016/j.ssci.2017.05.006
0925-7535/

that geographic information system (GIS) is also a promising IT innovation for improving construction safety site planning and risk management (Wang et al., 2014; Bansal, 2011; Naik et al., 2011; Bansal and Pal, 2009; Kimmance et al., 1999). Table 1 shows a summary of research on IT innovations applied to construction safety. Furthermore, currently available commercial safety management related software have also been reviewed and summarised in Appendix A for reference.

There are several drawbacks of these commercial systems: First it is hosted by a third party, which means a fee need to be paid and limited space may be provided; Second it is time-consuming and uneasy to customise the system to match with your organisational and project settings; Third, it is difficult to provide real-time communication; Forth, it is uneasy to use an App on mobile devices; Fifth, most of these systems are general systems and not specific to safety management, which means some safety functions may not be included; Sixth, many of these systems do not have GIS and GPS function built in, which make them unsuitable for horizontal type infrastructure projects such as road and rail construction projects. As such, there is a need to undertake research and develop a cloud-based safety information and communication system for infrastructure construction.

Many researchers recognised that safety information flow is the core of an effective safety management system (Kirwan, 1998; Bottomley, 1999; Cheng et al., 2012; Fernández-Muñiz et al., 2009; Wilson and Koehn, 2000; Zhou et al., 2015), though there are only few reports that have addressed the need for real-time communication of safety information between construction workers (El-Saboni et al., 2009; Nuntasunti and Bernold, 2006). An effective system does not only have positive impact on safety of construction workers but also ensure that employers comply with relevant legal requirements (Fernández-Muñiz et al., 2007). In contrast to the advancing of IT applications in construction safety as described above, current safety information and communication management systems, as shown in Fig. 1, are not fully utilising currently available IT. The current system is still by and large utilising paper-based documents to capture and store safety information. The paper-based documents are then scanned and stored in the relevant safety directory. There are three issues of the system: First, safety information is not available in real-time; Second, it takes considerable administrative efforts to digitise paper-based documents and to file them correctly in the safety directory; Third, it is difficult to track the digitised information in large-scale infrastructure construction projects. Hence, there remains a need for more efficient and effective safety information management systems for construction.

This paper aims at designing and developing an innovative system for communicating and managing safety information in infrastructure construction projects. Due to the fact that most of the safety data and information in infrastructure construction are location-based, systems that have spatial data management and analysis features would be more suitable. In order to achieve efficient safety data/information capture and sharing, the systems should be able to process information in real-time. The recent emerging of cloud computing provides capabilities for processing large amount of highly complicated data in real-time (Armbrust et al., 2010; Bhat et al., 2011). Therefore, this research will develop a cloud-based GIS, herein called *Safety Information Management System* (*MapSafe*). The system developed in this research is expected to exhibit the capability to capture both the project data and on-site safety data with location information and to be able to share the processed safety information in real-time. The system will be fully self-contained within a cloud for maximising system flexibility and adaptability. Moreover, project information including design drawings and BIM for each individual construction element should also be accessible through *MapSafe*, thus enhance the practice of construction safety management.

Table 1
Summary of IT innovation applications in construction safety.

IT Innovation	Safety application	Authors (Year)
BIM (building information modelling)	Safety site planning	Azhar et al. (2012)
	Safety in design	Eastman et al. (2009)
	Safety risk management	Hartmann et al. (2012)
	Safety in design	Hayne et al. (2014)
	Safety in design	Hu et al. (2008)
	Safety risk management	Melzner et al. (2013)
	Safety site management	Park and Kim (2013)
	Safety knowledge database	Vossebeld and Hartmann (2014)
	Safety site planning	Wang et al. (2014)
	Safety in design	Zhang and Hu (2011)
	Safety risk management	Zhang et al. (2015)
	Safety risk management	Zhang et al. (2013)
GIS (geographic information system)	Safety site planning	Bansal (2011)
	Safety risk management	Bansal and Pal (2009)
	Safety monitoring	Kimmance et al. (1999)
	Safety site planning	Naik et al. (2011)
	Safety site planning	Wang et al. (2014)
Location tracking device	Safety risk management	Baertlein et al. (2000)
	Safety site planning	Cheng and Teizer (2013)
	Safety monitoring	Lee et al. (2009)
	Safety site management	Park and Kim (2013)
	Safety prevention system	Teizer et al. (2010)
	Safety prevention system	Yang et al. (2012)
MGS (machine guidance system)	Safety risk management	Baertlein et al. (2000)
	Safety risk management	Talbot and Nichols (1999)
VR (virtual reality)	Safety site planning	Cheng and Teizer (2013)
	Safety training	Guo et al. (2012)
	Safety site planning	Guo et al. (2013)
	Safety risk assessment	Hadikusumo and Rowlinson (2004)
	Safety risk assessment	Hadikusumo and Rowlinson (2002)
	Safety monitoring	Han et al. (2009)
	Safety site planning	Huang et al. (2007)
	Safety site planning	Lai and Kang (2009)
	Safety site planning	Li et al. (2003)
	Safety site management	Park and Kim (2013)

2. Current safety management system

This section provides an example of a construction company's typical safety management system for context and clarity. *COMPANY T* is a multinational construction organisation based in Australia. This company adopts a six-level safety management framework for its global operations (Fig. 2). The framework is topped by the company's safety vision and values. Safety vision and values are important to all workers within a company. A clear and sound safety vision not only provides the certainty and clarity of safety commitments within the company to the workers but also sets the foundation for a strong workplace safety culture amongst the workforce together with well-defined values. The safety vision of *COMPANY T* is that "safe projects are successful projects and that all injuries are preventable".

The second level of *COMPANY T*'s safety management system is about policies. Safety policies are developed based on safety vision and values to explicitly express principles and guidelines for achieving the safety objective of a company (Fernández-Muñiz et al., 2009). Effective safety policies are important in the construction industry because they provide clarity and boundaries as well as approaches for performing different tasks and duties, thus shaping the safety culture within the company. The policies of *COMPANY T* are "strong leadership, everyone's commitment, best-