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ScienceDirect
Procedia Engineering 123 (2015) 125 – 134
Procedia Engineering
www.elsevier.com/locate/procedia

Creative Construction Conference 2015 (CCC2015)

Positive safety participation and assessment by integrating sharing technology with virtual reality

Dong Shuang [a,b*], Yin Qin [a], Li Heng [a]

[a] *Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong*
[b] *Department of Construction Engineering Management, Tongji University, Shanghai, China*

Abstract

Traditional health and safety performance in construction is assessed based on accessible outcomes such as accidents, injuries, illnesses and diseases. This lagging measurement still exists and is used by many industries since it is preferable for data collection, understandable to the majority, objective and valid. Many researchers are starting to treat the performance assessment in a much more proactive way by taking safety climate and culture into consideration. In current practice, as an indispensable part of safety climate/culture, safety participation level is merely evaluated by passive survey questions like "Have you attended the safety training", which ignores many invisible participation behaviors like safety knowledge transfer and sharing. What's more, although many traditional safety performance assessments are intended to modify construction workers' safety behavior, study on personal level safety assessment is still absent.
To solve the problems above, this study firstly presents a systematic safety performance assessment framework on personal level, including not only traditional lagging indicators, but also positive indicators like participation and attitude. This framework is substantiated by comprehensive literature review. Then a positive safety participation and participation assessment method is designed by integrating sharing technology with virtual reality. The feasibility of this method is tested on a real worksite.

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015

Keywords: Personal safety performance; Assessment; Knowledge sharing platform; virtual construction.

* Corresponding author. Tel.: 0852-53155691.
E-mail address:rosine.dong@connect.polyu.hk

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015
doi:10.1016/j.proeng.2015.10.069

1. Introduction

Safety performance and its improvement on constructions site has been a chronic problem. It has received a great deal of attention since long time ago like when the implementation of Occupational Safety and Health Act in 1970. The ability to measure safety performance is a key factor for a reliable check of safety training effectiveness, safety management methods and safety improvement [1]. At first, safety performance was directly related to the outcomes from first aid injury to fatality [2], but the dis-illusionary fact is a low injury or ill-health rate, even over a period of years, is no guarantee that risks are being controlled and will not lead to injuries or illnesses in the future [3]. Therefore many further studies in safety measurement focused on measuring whether behaviors follow the safety regulations [4]. At this stage, health and safety differ from many other areas because its better performance comes from the absence of an outcome (injuries or illness) rather than a presence. All these measures are based on the pessimistic assumption that almost all organizations are typified by greed, selfishness, manipulation, secrecy, and a single-minded focus on winning. In more recent years, there has been a trend toward taking positive organizational factors into consideration like trustworthiness, resilience, wisdom, humility, high levels of positive energy [5]. Accordingly, health and safety measurement methods put an increased emphasis on ideas of "goodness" and positive human potential instead of errors and mistakes before. This multiple-dimensional health and safety performance becomes achievable by the addition of safety participation and safety climate on safety outcomes and compliance assessment [6].

Although there have been many personal safety performance methods in other industries like mining, manufacturing [7] or health service [8], the construction industry with complex and changing conditions seriously lacks of practical, reliable and valid measure of individual safety performance [9]. As a result, this research comes up with a comprehensive individual health and safety performance assessment framework based on literature review as the second part. To achieve the practical goal, a new method is designed and the supporting system is developed to assess the individual safety participation automatically and quantitatively by integrating Sharing App with Virtual Location Technology.

2. Systematic Health and Safety Performance Assessment

2.1. Health and safety performance assessment

In this part, a hierarchical individual safety performance framework and corresponding systematic assessment indicators are identified and interpreted through related literature review. The occupational health and safety (OHS) performance has traditionally been measured by outcomes such as accidents, injuries, illnesses or diseases [10] completely above water surface in Fig. 1. This lagging measurement still exists and is used by many industries since it's relatively easy to collect data, easily understood, objective and valid [11]. Since these outcomes occur unpredictably and only rarely, they are normally not given to direct observation. For these reasons most methods are based on post-factum measurement. However, these "after the fact" indicators plunder the opportunity of prevention and correction in time and cannot bring safety attention or improvement to the next project when the outcome is relatively good before. What's worse, the bad outcomes are always under-reporting [3].

As human behavior accounts for major causes of the accidents, many researches treat safety issue in a much more proactive way [12-14]. Safety compliance indicators refer to following the rational safety regulations and plan which constitute a key part of behavior based safety (BBS) methodology as BBS is aiming at intervening and modifying human unsafe behaviors [15] where primary attention is directed at specific safety-related behaviors that are, typically, performed by workers [16]. What's more, according to the empirical study about construction individual behavior [17], workers' behaviors related to safety could be classified into personal safety behavior (PSB), structural safety behavior (SSB) and interactive safety behavior (ISB). PSB pertains to safety compliance while SSB and ISB belong to safety participation category as shown in Fig. 1. These participation indicators are relatively extra requirements and supportive actions to raise better safety climate/culture where the similar items are safety involvement and communication [18].

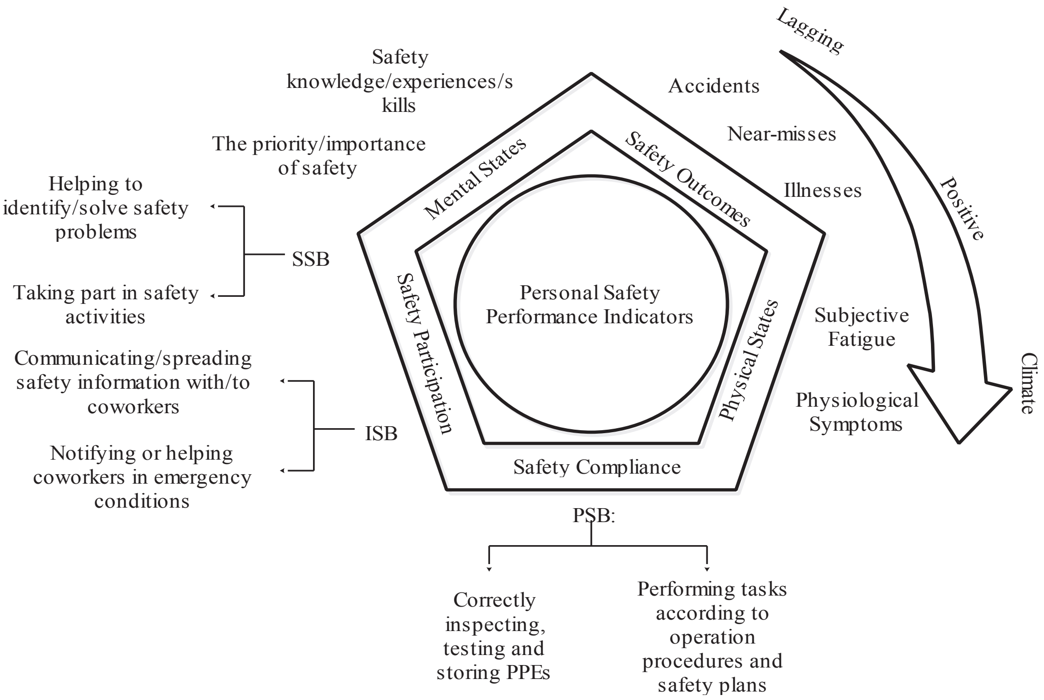

Figure 1. The systematic individual safety performance assessment indicators

Being foundation of the hierarchical assessment framework shown in Fig. 1 and also the important components of safety climate/culture, construction workers' attitudes and perceptions of worksite safety are involved in evaluating indicators. In accordance with cognitive model, perception is the first step of psychological process, and the only part directly contacted with memorized information which is represented by knowledge and skills [19] while attitude refers to an individual's positive and negative judgment of performing a behavior [20]. At the same time, physical state is proposed to be effective safety performance indicator due to the fact that fatigue and many negative physiological symptoms could make worker feel physically stressful [21], cause physical injuries of overexertion [22] and even ergonomic and degenerative disorders [23]. Research Committee on Industrial Fatigue (1969) designed and released subjective symptoms to predict fatigue by 30 standard questionnaire questions classified into "drowsiness/dullness", "concentration difficulty" and "physical disintegration". Meanwhile, other physiological measurements like heart rate, blood pressure, calf circumference, critical flicker fusion and strength have been utilized as useful indexes for health and safety assessment [24].

2.2. Safety participation assessment issues

Since safety climate and culture have obtained tremendous attentions in these years, many methods and indicators turn up to assess personal participation. Safety participation was conceptualized as the behaviors that may not directly contribute to workplace safety, but do help to develop an environment that promotes safety [25]. The main categories of safety participation include helping, voice, stewardship, whistleblowing, civic virtue and initiating safety-related change [26]. To link agreed safety goals at workplace to the actions required to achieve them and to identify and facilitate the removal of barriers to the implementation of those actions, multiple indicators have been developed as a quantitative method.

In fact, comprehensive measures are rarely used due to a practical concern, length of these measures, which has been noted as a problem in studies all the time [27]. The popular indicators, for example, times of attending voluntary safety meetings and training [28], assisting coworkers to perform safely, stopping safety violations [9], expressing and transmitting information about safety [29], are assessed through human observers and hard to practice effectively in massive scale. These subjective assessment methods are not reliable to provide the same measures when assessed by different people [30] because these observations are highly experience depended and bias-easy. As a result, the next part establishes a practical and objective method to assess worker's safety participation performance by sharing and virtual technologies.

3. Methodology

3.1. General methodology

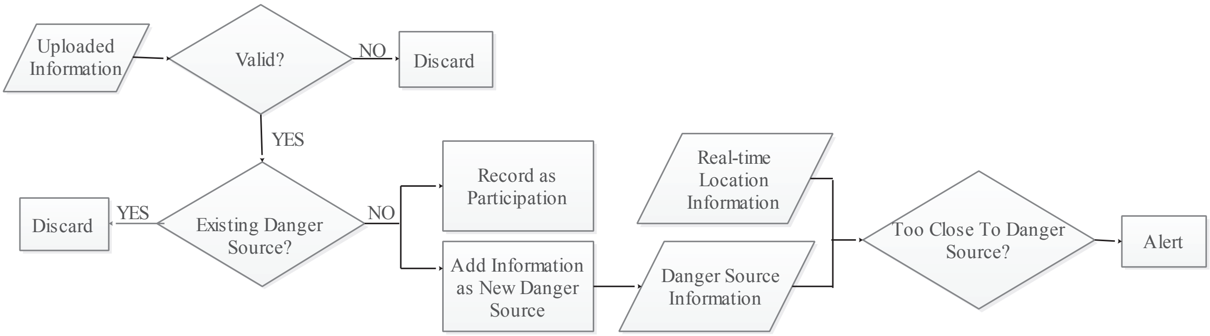

Figure 2 General methodology

As shown in figure 2, the general methodology is to realize two functions: supporting safety participation and keeping the worker away from danger source. The safety participant makes a figure by capturing and uploading the danger source information. Once the uploaded information is testified as a new danger source non-existent in present database, the related information will be added in the system and a tag will be fixed on the new danger source on work site for further in-time warning and protection. Meanwhile, the information of the up loader, such as ID, name, and trade will be recorded in the safety participation assessment system. Furthermore, the real-time locations of workers and danger sources are calculated, and if the worker is too close to any danger source, the warning will be sent to him/her through the tag on helmets.

3.2. General system architecture

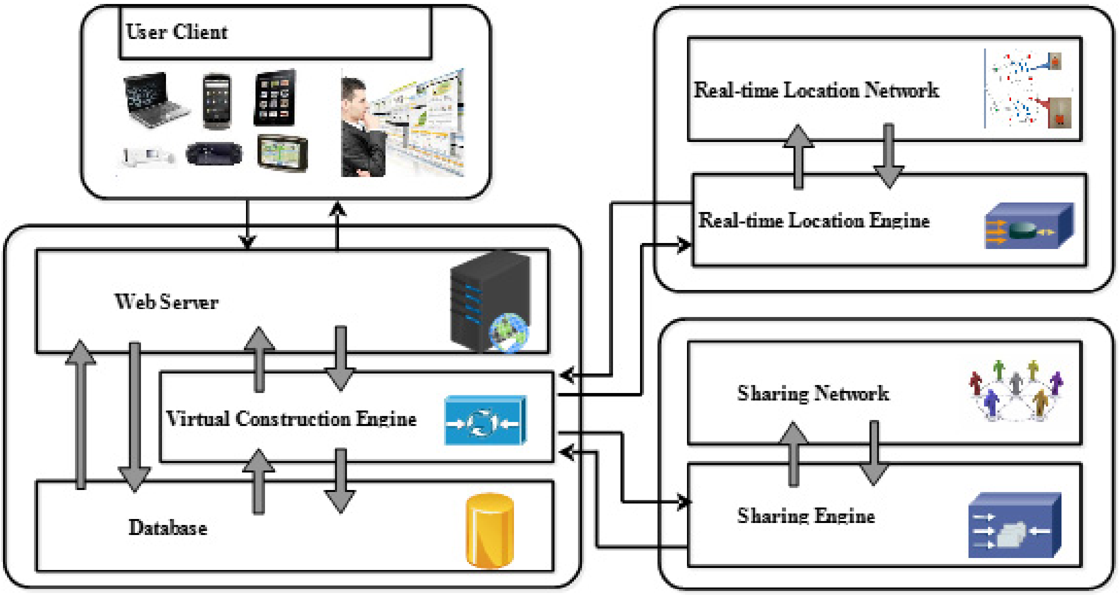

Figure 3 the general system architecture

This multi-user on-line supporting system consists of three main parts shown in figure 3: Real Time Location System, Virtual Construction System and Safety-related Sharing System. Respectively, Real Time Location System is responsible for detecting and calculating the timely locations of tagged objects like workers, danger sources and equipment, while Virtual Construction System is responsible for displaying the relative 3D positions on building models and recording the moving of all tracked objects. Meanwhile, the Safety-related Sharing System is a platform for workers to upload photos and information about new danger sources or hazardous behaviors, and the records are used in participation performance assessment. The whole system adopts a typical three-tier web-based application structure composed of presentation layer, business layer and data layer.

3.3. Safety participation platform

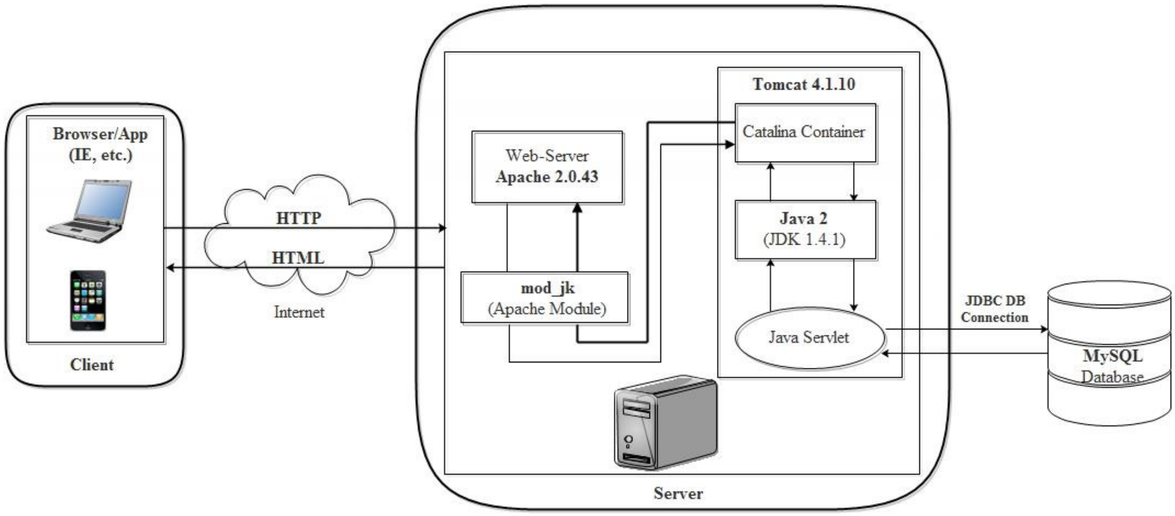

Figure 4 Sharing Platform Deployment Architecture

This platform is developed to collect information about danger sources identified and shared by workers. To ensure user-friendliness and outcome visualization, a browser and an application are designed for computer and smartphone respectively. Apache Tomcat, which powers numerous large-scale, mission-critical web applications across a diverse range of industries and organizations, is used and programmed as the webserver to process information uploaded, make records and do statistical calculation. All the information and outcomes are stored in SQL database for further analysis. Every worker needs to set up an account which is matched with his/her worker ID, and their uploading and sharing records are applied as the foundation of safety participation assessment both in horizontal and longitudinal ways.

3.4. Real-time location system and virtual construction

Real time location network is constructed by tags, which are small hardware devices designed to be mounted on helmets and moving objects, and anchors that are fixed at some static positions as reference points. Chirp Spread Spectrum (CSS) technology is employed for ranging, which estimates physical distance between two devices by Time of Flight (TOF) of radio frequency signals. The location-based virtual construction comes true with the help of Location Engine, SmartFoxServer and Unity. The location engine is programmed to calculate tags' positions, and then send the position information to the application server. It also takes charge of relaying warning signals to Location Network as a sound or vibration trigger. The warning signal is triggered by tag coordinate calculations. This calculation process is programed according to Java.awt.geom and Polygon2D algorithms. All the programming is developed on SmartFoxServer. A Server Object Extension is also developed in the application server to drive and synchronize all the User Clients in terms of the real construction situations. Unity is used to build the User Client for visualizing construction progresses, defining static and dynamic dangers, as an integrated authoring tool for creating 3D video games or other interactive content such as architectural visualizations or real-time 3D animations. The connection and information transformation between the network and location engine on computer is carried out by the application of the NanoLOC TRX transceiver, which is the only wireless devices using CSS with real time location and RFID abilities.

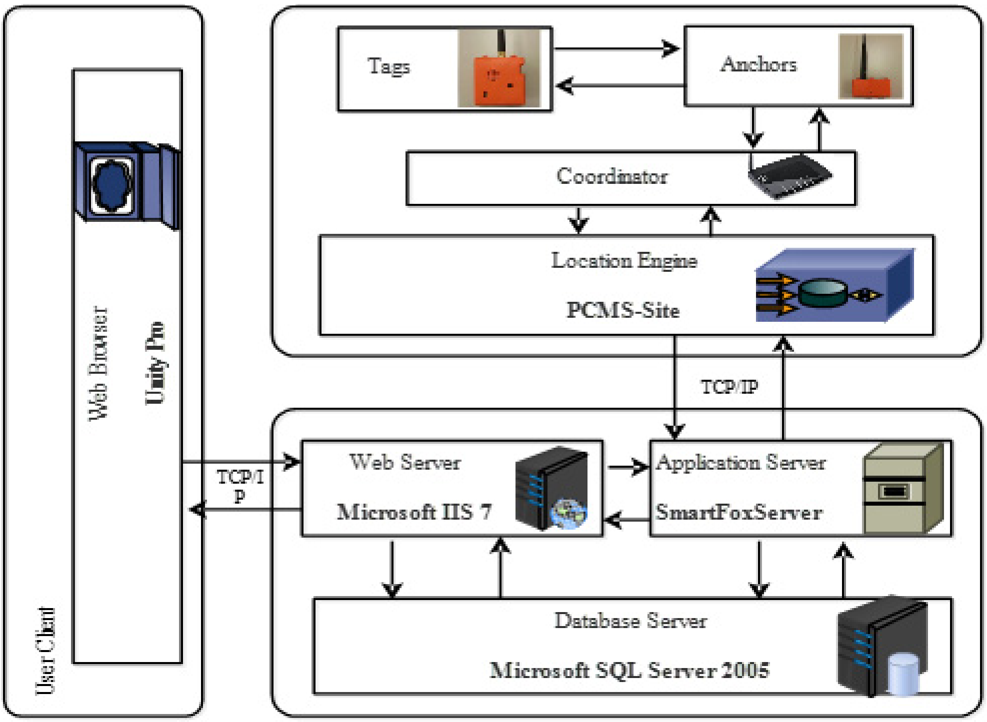

Figure 5 Real-time location and virtual construction system

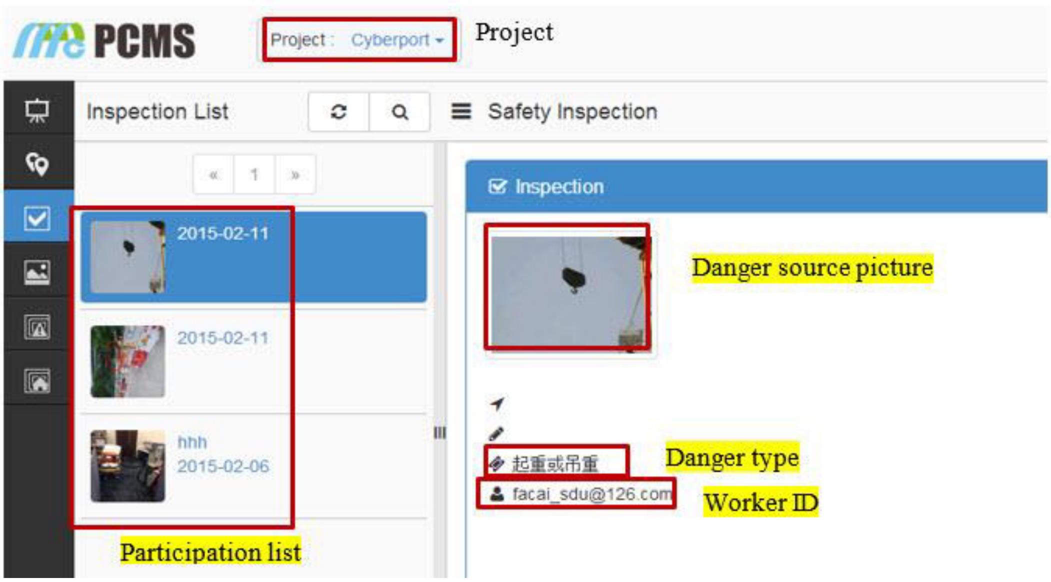

Figure 6 Safety Participation Records Website

4. On-site Experiment

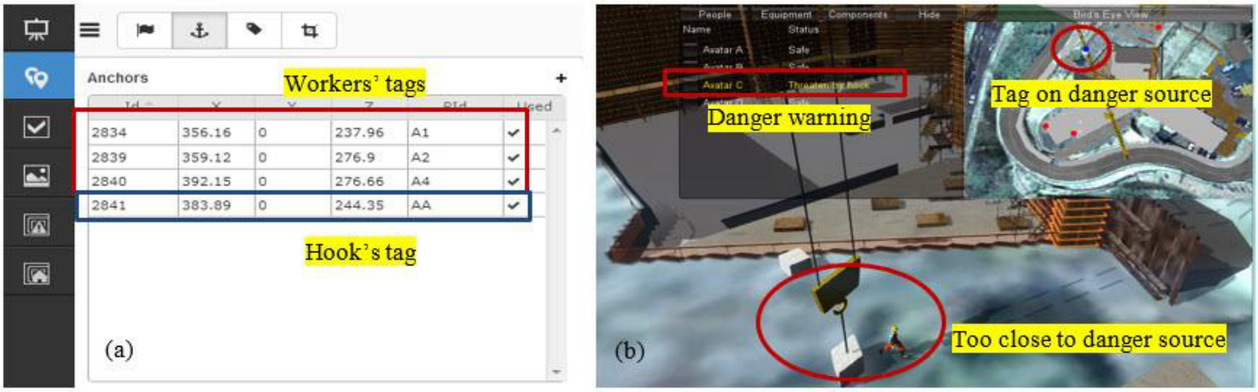

Figure 7 (a) Adding information; (b) Location synchronization and visualization

In order to demonstrate the feasibility and validity of this proposed safety participation assessment method, it is necessary to test this on-line system on real working sites. A sloping construction site with many tower cranes is selected as this kind of project is very common and accident-prone in mountainous Hong Kong. As a potential danger source, the moving lifting hook was recognized and its info was uploaded on the application as shown in figure 6. Workers on worksite captured photos of the crane. Then the related information like project name, type of danger and worker ID, were added as in figure 6 in the sharing system. And the sharing activities were recorded to calculate how many times each worker participated in safety information sharing during a certain period of past time.

To further promote safety climate and performance, the uploaded information was both deployed in the warning system and on real site as in figure 7. In this experiment, three workers working in the crane area were selected to participate the study, and a hook on site was fixed with tag for location tracking. The tags were matched with the personal and danger information, such as work type, danger type, warning type and threshold distance as shown in figure 7. The real time moving of these four objects were synchronized in 3D model in figure 7.During the work time, once the tracked worker was too close (smaller than 2m in this case) to the moving hook, the warning would be sent to the worker as in figure 8 through the tag on his/her helmet to remind him/her to step away from the moving danger source. All these moving paths and warnings were recorded for further possible safety performance analysis.

5. Conclusions and Future Work

Traditional safety performance assessment methods escape from personal level and have failed to be widely effective because they are highly dependent on manual and experienced inspection process with lagging assessment indicators. This paper solves these two problems by providing a framework for systematic personal safety performance assessment and then developing a practical approach for personal safety participation assessment. This involved the development of a supporting multi-user platform to sharing safety-related information and also protecting the workers from danger sources through obtaining real-time locations. A controlled experiment on real construction site was conducted to verify the ability of the method to support personal safety performance.

Acknowledgements

The work was supported by the Innovation and Technology Commission (ITC), Hong Kong Special Administrative Region, under the project "Location-based Technologies for Asset Tracking and Risk Management" (ITP/036/12LP), a General Research Grant titled "Proactively Monitoring Construction Progress by Integrating 3D Laser-scanning and BIM" from the Research Grants Council of Hong Kong (Reference No. PolyU 152093/14E), and the National Natural Science Foundation of China (Grant No. 71390523).

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