
Creative Construction Conference 2016

# On-site Mobile Application for Command, Control and Communication of Safety and Quality

Igal M. Shohet, Lorenzo Ciabocco*

*Department of Structural Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel*

**Abstract**

Safety and quality are two factors that play an important role in construction projects success. Management involvement in safety, effective communication and control during the construction phase have been identified as fundamental parameters that lay the foundations for effective construction. Focused on the emerging mobile computing technology, smartphones and tablet, an application for command, control and communication of construction safety and quality management was developed. The application makes use of tags, which are physically attached to the workers and equipment (such as scaffoldings, formworks and crane). All safety procedures can be implemented using the application, including, safety specifications, safety and quality checklists, forms, reports, safety risk assessment and safety and quality audits and records. The information can be accessed on real-time by all members of the project management team and senior company levels. To evaluate the applicability, the system was implemented in a pilot project. Safety and quality key performance indicators were established and implemented prior, during and following the implementation in order to examine and quantify the potential benefits. The observation of the key performance indicators provided a clear evidence of the potential of the proposed mobile application in improving both safety and quality of construction activities.

**Keywords:** Communication, control, mobile application, quality, safety management.

## 1. Introduction

Safety and quality in the construction industry are continuously under the spotlight of safety and quality control [1, 2]. In spite of the efforts to enhance safety performance construction fatalities and injuries continue to be a worldwide plague [3]. According to the Ministry of the Economy [4, 5], the Israeli construction sector continues to collect the highest death-toll compared to all others sectors of economy. In the years 2012 and 2013 construction industry mortality accounted for 52 and 50% of the total industry death toll [4, 5]. Furthermore, injuries and fatalities cause inestimable suffering, and are also associated with considerable financial expenditures caused by disabilities and early retirement [6, 7]. Besides, the cost of quality deviations in the construction industry has been found to be significantly high. Activities required repairing quality deviations represent a significant factor that contributes to cost and schedule overruns [8]. Burati et.al. [9] indicated that quality deviations in the projects accounted for an average of 12.4% of the total projects cost and Love et.al. [8] found that rework contributed to 52% of the project's cost growth. Thus, an integrated safety and quality management system could be useful tool to reduce the occurrence of injuries and fatalities and complete a construction work on schedule and within the allotted budget [1].

Management involvement, effective communication and control during the construction phase have been identified as fundamental parameters that lay the foundations for the safety and quality climate in construction. Furthermore, in literature there is a large qualitative consensus for integrated quality and safety management [2, 10, 11]. The advent of smartphones with the state-of-the-art of the mobile computer technology provides an important opportunity to improve the existing process of on-site construction management [12]. Although the recent attention by the researchers in the use of Information and Communication Technology (ICT) in construction

* Corresponding author. Tel.: +972-8-6479682; fax: + 972 8 6479670.
*E-mail address:* ciabocco@post.bgu.ac.il

[13], no empirical studies have yet investigated the use and benefits of the ICT for an integrated safety and quality management in construction. Exploiting the emergence of the mobile computing technology, the present study aimed to propose and test the above-mentioned system.

## 2. Background

### 2.1. *Safety and Quality in Construction*

Safety in the construction site is a complex phenomenon impacted by multiple factors such as the design quality, planning, safety equipment, workers safety qualifications, safety management, and control [14]. In order to investigate these factors, Choudhry and Fang [15] interviewed construction workers who had been accident victims. Management involvement and communication were found to be the most effective factors to encourage and facilitate site safety. Along the same line, Mohamed [16] concluded that both management commitment and communication are prerequisites to create and sustain a positive safety climate in the construction site. This conclusion was also reached and supported by other studies [17]. In addition, effective control by the site manager through inspections, supervisory key factors and over the subcontractors plays an important role to enhance construction safety. Abudayyeh [17] conducted a survey concluding that the injury and illness incidence rates of companies that performed safety inspections were significantly lower than those who did not. Zhang [3] revealed that about one third of the workers' unsafe behavior, which is the main cause of accidents, caused by lack of managerial or supervisory activities, and Mohamed [16] found that supervisory practices have a positive influence on the safety climate. Teo [18] reported that a major concern of the site managers, during the construction process, is the effectiveness of control over the subcontractors, as high number of subcontractors increases the probability of poor communication, coordination and control, and consequently the chances the likelihood of accidents.

Loushine [1] examined the definition of quality used in the literature. Researchers in construction gave the following definitions for quality performance: meeting expectations of the customer, reduced rework or defects, repeat business and completion on-time and within budget. Rework which was defined [10] as the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time. There are various forms that may require rework such us quality deviations and failures, nonconformance and defects [8]. Although rework is often associated with design related issues, a greater number of rework-related incidents tend to occur during the construction phase [19]. Love et.al. [19] studied the construction quality by identifying the factors that influence rework in projects. Lack of quality management, poor communication, and poor supervision and control were found as key factors that contributed to reworks occurrence. Along the same line, Arditi [20] found that during the construction phase, effective control and communication enhance the quality of the building process.

### 2.2. *Synergy between Safety and Quality*

Pheng and Pong [21] confirms that there are similarities between safety and quality management systems, and it make possible to integrate these two processes to achieve better co-ordination and utilization of scarce resources. Hursul et al. [11] argues that the similarity of the safety and quality functions and the fact that they operate simultaneously in the same environment leads to the conclusion that it might be beneficial to combine or at least closely coordinate the management activities. Hoonakker et al. [22] found that implementation of quality management systems in construction contributed to enhanced safety.

Despite the above findings, there is a lack of empirical studies to validate this hypotheses. In fact, only two recent researches had stressed this relationship empirically, by analyzing safety and quality data obtained from construction projects. Wanberg et al. [2] have provided an empirical evidence for a positive relationship between construction safety, and quality performance. Empirical data from 32 construction projects suggest the following relationships: (1) recordable injury rate is well correlated to rework, and (2) the first-aid rate is well correlated to number of defects. Trough interviews to project manager, it was identified that the reasons of these positive correlation are in the fact that rework involves demolition, schedule pressure and unstable work processes. Love [10] analyzed safety and quality data resulted from quality non-conformance, and found that 19 percent of safety incidents can be explained by rework.

## 3. Objectives

This research developed a mobile application for command, communication and control of construction (C4) safety and quality. The rationale behind this theme is the hypothesis that a synergy exists between high safety and high quality standards and vice-versa, and that a mobile application for the communication and control of these key construction subjects will introduce safety and quality in construction. An implementation of the application in a pilot study followed the development of the application to demonstrate and examine the applicability of the application. The objectives were as follows:

- To develop the C4 mobile application for continuous improvement of safety and quality performance in construction projects;
- To examine, measure and quantify the potential benefits resulting from the implementation of the system in a pilot project, through the use of safety and quality key performance indicators.

## 4. Description of the C4 mobile application

The $C^4$ mobile application aims to develop an innovative solution to continuous improvement of construction safety and quality by providing enhanced capabilities for control, learning and implementation of all measures necessary to ensure safety and quality. The proposed solution relies on mobile cloud-based system and of the methodologies for managing safety and quality according to the principles of the relevant Israeli Standards (e.g. 904 (formworks for concrete) [23], 118 (concrete) [24], 466 (concrete structures stability) [25]) and following the safety regulations of construction operations. The developed application allows ensuring that before workers start to perform a certain activity, action, place, time and people entitled to the operation are uploaded in the system. Tracing and documentation are carried out in few seconds by scanning the barcode label smart, using a mobile phone or tablet. Each tag code is unique to each asset and workers. The scan function allows the holder to make all relevant information, including: safety specifications, safety and quality checklists, forms, reports, safety risk assessment and safety and quality audits and records related to the place or the equipment it comes into contact with them, as showed in Fig.1. Construction managers and foreman are in charge to register workers and work tasks information, including description, location duration, workers and supervisors in charge. The asset information is automatically stored in the cloud system and transfer (through simple scan) to a barcode attached in the area of the task on the spot. Workers who are assigned to the activity confirm directly in the application prior to beginning, through the use of their smartphones or tablets, that they received appropriate safety training and that they have all personal protective equipment required. They also have to check and report the risks and hazards related to the activity. To stimulate the respect of the safety issues, supervisors are able to give positive or negative feedback to workers according to their performance. The $C^4$ mobile application proposed in this study makes it easier for officials and employees in charge of it, to maintain a simple and effective risk and quality assessment unified and built-in control real-time instances of forgetfulness and human errors, and therefore help reinforce the learning and internalizing awareness of safety risks and construction quality at work.


Figure 1. Activities and reports of the $C^4$ mobile application

## 5. System implementation and monitoring

The proposed system was tested on a construction site in Ramat Gan (Israel). The project is a residential building with a total of 34 floors above ground and with an average floor area of 550 sq.m. The total cost is estimated at 25. 8 million dollars and the duration is 3 years. The workforce is made up of 30 workers, with one main contractor and several subcontractors. This project represents one of the main challenges for the engineers because of the small plot of land where it is realized.

### 5.1. *Safety Indicators*

In this study safety performance indicator was defined in terms of worker's behavior. This because, the literature review has been demonstrated that unsafe behaviors of workers are directly related to safety problems. Observations (safety samplings) regarding worker's behaviors were conducted by the authors one round per week at the same days and hours. This to eliminate the effect of the daily and weekly variations of performance. At least four hundreds data points were collected at the site in each safety sampling. Forty observations were carried out at constant intervals of two minutes for a crew of formworkers, which includes between ten and twenty workers. Fixed interval technique is valid, dependable, considered credible by construction safety experts and it is particularly adaptable to the study of short-cycle, highly repetitive group operations [26]. Individual behavior was graded according to the following categories: "remarkable safe behavior", "safe behavior", "risks himself", "risks others" and "risks himself and others".

Performance score was generated at each safety sampling and the final score was assessed on two different aspects:

**Safety Indicator 1 (S.I.1)**, which represents the quality of safety behaviors. It is calculated as showed in Eq. (1).

$$S.I.1 = \sum_{i=1}^{5} Pi \cdot Wi \qquad (1)$$

Where, *Pi* is the percentage of the behavior detected for each category, and *Wi* is a correspondent weight assigned at each category, as follows: (1) remarkable safe behavior, (0.75) safe behavior, (0.5) risk himself, (0.25) risks others and (0) risk himself and others.

**Safety Indicator 2 (S.I.2**), which represents the percentage of safe activities. It is calculated through the division between the number of safe observations (marked under remarkable and safe behavior categories) and the total number of data collected, as similarly used in [3].

### 5.2. *Quality Indicator*

Number of reworks, in this case, (or/and the related additional cost and hours) could not be taken into account as a quality indicators because the analysis of the project diaries showed an under reporting of the performed reworks. In addition such measure of quality is not adequate to monitor the weekly variation of quality performance. Thus, the quality indicator was set up through direct in site observations. The quality indicator (Q.I.) used and developed in this study enables to evaluate the overall quality of the construction work. Q.I. is defined by a value between 0 and 100 which expresses the quality state of the reinforced concrete works performed. Its score is calculated every week through structured quality samplings.

In-depth investigations of three quality aspects of the performed reinforced concrete works were carried out: (1) the concrete works, (2) steel works and (3) formworks. In each of the above mentioned categories keys quality parameters were inspected and marked according to a five point rating scale. For example for the steel works, following parameters were observed: the adherence of the specifications (through the consultation of the blueprints), the concrete cover (through the control of its measure and the correct use of the spacers) and the correct installations of the rebars (through the control of the implementation and the ligature between them). For each parameter, the percentage of the correct work was recorded. Similar procedure was developed and implemented concrete and formworks. The final score of the Q.I. is calculated by the average of the score of the three categories. This indicator enables to evaluate the overall quality construction of the reinforced concrete works performed every week and to monitor its value over time.

### 5.3. *Monitoring of the Safety and Quality Performance*

The phases involved in monitoring the trend of the safety and quality performance, resulted from the implementation of the mobile $C^4$, were as follows:

**Phase I.** Baseline phase: it is the starting level of the safety and quality performance. It was identified through the first in-site surveys.

**Phase II.** Implementation phase: it is the phase, after the baseline phase, during which the $C^4$ application is working. Safety and quality observation were carried out along the implementation upon achievement of convergence of the findings.

## 6. Findings

This chapter describes the findings resulted from in-site observations performed by the research team during 11 weeks. These observations consist of 2 weeks of base-line phase, and 9 weeks of implementation phase. The average score of the Safety Indicators during the base-line phase were found to be extremely low as shown in Fig. 2. It was due to a limited involvement of the first and mid-line managers to the safety regulations. The main unsafe behaviors and activities detected during this phase were: (1) workers avoided the use PPE (Personal Protective Equipment) (2) unsafe load lifting (3) work in high position without a secure platform (4) climb the formwork and (5) throw objects between workers. Besides, site layout conditions were under low level of organization, in terms of safety of crossing, protection of falls, protection shaft, density, order and organization in general.

A significant improvement of safety performance was observed following the implementation of the application. The convergence of the score of the safety indices was achieved after 7 weeks of implementation. Fig. 3 shows the distribution of the worker's behaviors observed during the sampling performed in the second week (base-line phase), and Fig. 4 shows the distribution at the tenth week (implementation phase). Comparison shows the large decrease in unsafe behaviors (categories n.1, 2, 3) with the consequent increase of the safe behaviors (categories n.4, 5), especially the remarkable safe behavior category (category n.5). Furthermore, a drastic reduction of unsafe activities (90.8% less) was observed as shown by S.I.2 in Fig.1. Fig.5 shows the trend overtime of the Quality Indicator between the two phases. Main quality problems observed at the start were as follows: (1) widespread segregations, (2) widespread leakage of concrete, (3) concrete surfaces not uniform, (4) insufficient concrete cover, (5) poor rebar works, and (6) poor formwork's quality. As for the Safety Indicators, Quality Indicator improves significantly during the implementation phase until reaching the convergence of the results after 7 weeks.

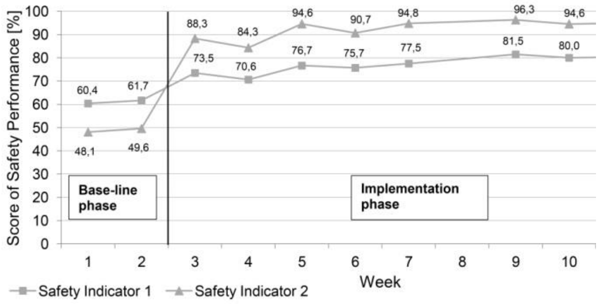

Figure 2. Trend of safety performance

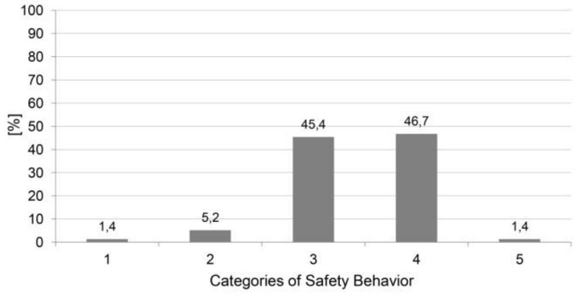

Figure 3. Distribution of safety behavior week n.2

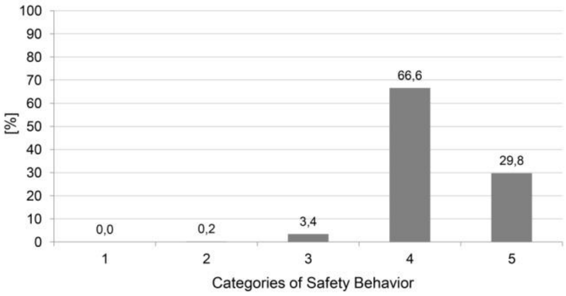

Figure 4. Distribution of safety behavior week n.9

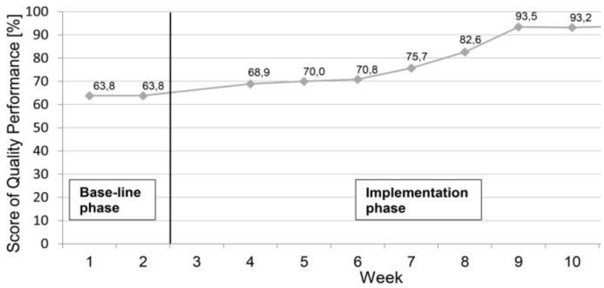

Figure 5.Trend of quality performance

A statistical analysis of the safety and quality key performance indicators, prior and after the implementation of the system, was carried out using the Student t-test. The differences of the safety and quality indicators between the two phases were found at level of significance of 99%. The study provides a clear evidence of the effectiveness and the benefits of the proposed system by stimulating site management involvement.

## Acknowledgement

The authors express their gratitude to the Israel Social Security foundation “Manof” for the generous support in this research.


## References


[1] Loushine, T.W., Hoonakker, P.L.T., Carayon, P., Smith, M.J. (2006). “Quality and safety management in construction”. *Total Quality Management 17(9), 1171-1212.*

[2] Wanberg, J., Harper, C., Hallowell, M.R., Rajendran, S. (2013). “Relationship between Construction Safety and Quality Performance”. *Journal of Construction Engineering and Management.*

[3] Zhang, M., Fang, D. (2013). “A continuous Behavior-Based Safety strategy for persistent safety improvement in construction industry”. *Automation in Construction 34, 101-107.*

[4] The Israeli Knesset, Data and Research centre, (23 Dec. 2013). “Data report on work injuries of construction workers” (in Hebrew).

[5] Ministry of Industry, Trade e Labor, Department of Ministry of Economy (2012) “Report on deadly accidents” (in Hebrew).

[6] Sawacha, E., Naoum, S., Fong, D. (1999). “Factors affecting safety performance on construction sites”. *International Journal of Project Management 17, 309-315.*

[7] Tuchsen, T., Christensen, K.B., Feveile, H., Dyreborg, J., (2009). “Work injuries and disabilities”. *Journal of Safety Research 40,* 21-24.

[8] Love, P.E.D. (2002). “Influence of project type and procurement method on rework costs in building construction projects”. *Journal of Construction Engineering and Management 128 (1), 18-29.*

[9] Burati Jr., J.L., Farrington, J.L., Ledbetter, W.B. (1992). “Causes of quality deviations in design and construction”. *Journal of Construction Engineering and Management 118 (1), 34-49*

[10] Love, P.E.D., Teo, P., Carey. B., Sing C.P., Ackermann, F. (2015). “The symbiotic nature of safety and quality in construction: Incidents and rework non-conformances”. *Safety Science 79, 55-62.*

[11] Husrul, N.H, Kamaruzaman, J., Hamimah, A. (2008). “Management of safety for quality construction”. *Journal of Sustainable Development 1(3), 41-47.*

[12] Kim, C., Park, T., Lim, H., Kim, H. (2013). “On-site construction management using mobile computing technology”. *Automation in Construction 35*(2013), 415-423.

[13] Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., Le, Y. (2014). “Information and Communication Technology in Architecture, Engineer and Construction Organizations: a 15-Years Review”. *Journal of Management in Engineering* 31(1).

[14] Khosravi,Y., Asilian-Mahabadi, H.,Hajizadeh, E., Hassanzadeh-Rangi, N. (2014). “Factors influencing unsafe behaviors and accidents on construction sites: a review”. *International Journal of Occupational Safety and Ergonomics 20(1),* 111-125.

[15] Choudhry, R.M., Fang, D. (2008). “Why operatives engage in unsafe work behavior: Investigating factors on construction sites”. *Safety Science 46,* 566-584.

[16] Mohamed, S. (2002). “Safety climate in construction site environments”. *Journal of Construction Engineering and Management 128(5),* 375-384.

[17] Abudayyeh, O., Fredericks, T.K., Butt, S.E., Shaar, A. (2006). “An investigation of management’s commitment to construction safety”. *International Journal of Project Management 24,* 167-174.

[18] Teo, A.E.L., Ling, F.Y.Y., Chong, A.F.W., (2004). “Framework for project managers to manage construction safety”. *International Journal of Project Management 23,* 329-341.

[19] Love, P.E.D., Edwards, D.J., (2004). “Forensic project management: The underlying causes of rework in construction projects”. *Civil Engineering and Environmental Systems 21 (3), 207-228.*

[20] Arditi, D., Gunaydin, H.M. (1998). “Factors that affect process quality in the life cycle of building projects”. *Journal of Construction Engineering and Management 124 (3), 194-203.*

[21] Pheng, L.S., Pong, C.Y., (2003). “Integrating ISO 9001 and OHSAS 18001 for construction”. *Journal of Construction Engineering and Management 129(3), 338-347.*

[22] Hoonakker, P., Carayon, P., Loushine, T. (2010). “Barrier and benefits of quality management in the construction industry: An empirical study”. *Total Quality Management 21(9), 953-969.*

[23] Israeli Standards Institution 1998. “ Formwork for concrete: Principles” Israeli Standard 904 part 1. (in Hebrew)

[24] Israeli Standards Institution 1986. “Concrete for structural uses: production control and compressive strength” Israeli Standard 118 (in Hebrew)

[25] Israeli Standards Institution 2003. “Concrete code: general principles” Israeli Standard 466 (in Hebrew)

[26] Laufer, A., Shohet, I.M. (1991). “Span of Control of construction foreman: situational analysis”. *Journal of Construction Engineering and Management,* 117(1), 1584-1592.