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Optimal allocation of resources in construction safety: Analytical-empirical model

Igal M. Shohet[a,*], Massimiliano Luzi[a,b], Matan Tarshish[a,1]

[a] Department of Structural Engineering, Faculty of Engineering Sciences, Ben-Gurion University of the Negev, Beer Sheva 8410501, Israel
[b] Formerly, Universitá Politecnica delle Marche, Department of Civil and Building Engineering and Architecture, via Brecce Bianche, 60131 Ancona, Italy

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ABSTRACT

Safety in the construction industry, as well as in the infrastructure sector, has always been a key issue. One out of six fatal accidents at work occurs in a construction site. Therefore, preventive measures such as investment in safety must be formulated accordingly. However, construction companies are often reluctant to invest resources in preventive activities. This paper seeks to investigate the optimal safety investment that should be allocated in preventive safety equipment and activities. To this aim, at first a field survey was conducted in 30 construction projects in Israel. Key safety parameters of the accidents occurrence, investment in safety, and accidents costs (direct and indirect) were statistically characterized. Then, a Monte Carlo simulation was developed in order to validate the survey and calculate the total costs of safety depending on the degree of investment in preventive safety, according to three levels: modest, standard, and high investment. The findings show that the optimal safety investment is 1.0% of the project scope. Because of the chaotic distribution of results there is a substantial uncertainty for investment of less than 1.0%. The direct to indirect cost ratio of accidents was found to be 1:3.07, in line with the other figures in literature.

1. Introduction

1.1. Problem statement

Safety in the construction industry, as well as in the infrastructure sector, has always been a key issue. The global construction and infrastructure industry exposes the workers to different occupational hazards which often results in fatal accidents. These hazards vary according to the work activities, safety culture, production pressure, and workers training. Hazard profiles are also different depending on the phase of construction. Therefore, the construction industry is a heterogeneous risk exposure area as many factors are involved in the construction process.

According to the International Labour Organization (2014), almost 2.3 million people are deprived of their life at work every year. About 350,000 of these deaths occur due to fatal workplace accidents and close to 2 million are from work-related deceases. It has been estimated that approximately 4% of the world's Gross Domestic Product (GDP) is lost due to direct and indirect costs of accidents and diseases (International Labour Organization, 2014). In Europe, the economic loss caused by workplace accidents is about 3.2% of the EU GDP (Rikhardsson and Impgaard, 2004).

According to ILO estimates, at least 60,000 of the fatal accidents in workplaces occur in the construction industry. In industrialized countries, deaths on construction sites stand at 25–50% of the total work-related fatal accidents (International Labour Organization, 2014). In Malaysia, construction industry fatalities are more than 3 times of other industries (Hamid et al., 2003). In Israel, the construction industry is responsible for almost 54% of the total fatal cases in work accidents (Knesset Research and Information Center, 2015). During the period 2010–2015, 184 workers were killed in work accidents while working in the construction sector (cf. Table 1).

The economic consequences and the severity of accidents are becoming a major concern in the construction industry; they are increasing the safety awareness and the need to abide by the safety rules. In 2014, the US reported about 201,000 work accidents in construction projects (Bureau of Labor Statistics, 2014b). The rate of fatal accidents in the US construction industry stands at 9.8 per 100,000 full-time equivalent workers (Bureau of Labor Statistics, 2014a), and the number of fatalities in construction in 2014, 899, was the highest reported since 2008 (Bureau of Labor Statistics, 2014a). Better figures are recorded in England: the rate of fatal injuries in the construction industry during

* Corresponding author at: Department of Structural Engineering, Ben-Gurion University of the Negev, Beer Sheva 8410501, P.O.B. 653, Israel.
E-mail addresses: igals@bgu.ac.il (I.M. Shohet), massimilianoluzi16@gmail.com (M. Luzi), tarshish@post.bgu.ac.il (M. Tarshish).
[1] Present/permanent addresses: Department of Structural Engineering, Ben-Gurion University of the Negev, Beer Sheva 8410501, P.O.B. 653, Israel.

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Table 1
The number of fatalities in the construction industry and the general economy in Israel during the years 2010–2015 (Table from "Work accidents in the construction industry", Knesset Research and Information Center, 2015, p. 6).

Year	Number of fatalities due to work accidents in the construction industry	Number of fatalities due to work accidents in all industries	Rate of fatalities in the construction industry
2010	26	52	50%
2011	38	64	59.4%
2012	31	60	51.7%
2013	32	62	51.6%
2014	31	62	50%
2015 (9 Dec)	26	43	60.5%
Total	184	343	53.6%

2015–2016 is 1.94 per 100,000 workers (Health and Safety Executive (HSE), 2016); however, the number of fatalities (43) are the same for the average between 2011 and 2014 (Health and Safety Executive (HSE), 2016), and they account for 30% of the total fatalities in all industries. In Israel, 62 fatal workplace accidents occurred during 2014, 31 of which were in the construction industry and mostly due to falls. The rate of fatal accidents in the construction sector per 100,000 employees is 11.53, the highest compared to the other industries (National Insurance Institute of Israel, 2014).

The problem of prevention of work accidents must be addressed at national level. Solving the problem at this level means dealing with the organizations' responsibility for prevention of work accidents. However, most organizations underestimate the importance of this issue and they calculate the costs associated with work accidents in an approximate way, mainly due to lack of knowledge and lack of reliable data and analytical methods to determine these costs.

Hamid et al. (2008) discovered that among the main causes of construction accidents there are: negligence of workers; failure of following work procedures; working at high elevation; failure to use safety devices and personal safety equipment; inadequate site management and lack of control; difficult work operations; poor workmanship; and poor workers attitude towards safety. Therefore, various and complex factors influence safety in the construction industry. Moreover, dynamic work environment as well as high work crews turnover expose the workers to unexpected and unfamiliar hazards (Helander, 1991). Insufficient training for safe work and lack of senior management support to safety also are two of the most influential factors responsible for safety in construction (Yung, 2009). Nevertheless, the support of upper management is one of the most cost-effective safety program that can be undertaken (Hallowell, 2010).

Similarly to Israel, the construction site safety in Palestine is neglected and poorly managed (Enshassi et al., 2007), and the lack of supervision is one of the main factors that influences the occurrence of accidents. Several studies have proven that lack of inspection/supervision of workers is among the main factors that affect safety in construction industry (Hinze and Raboud, 1988; Jannadi, 1996; Jaselskis et al., 1996; Lee and Halpin, 2003; Sawacha et al., 1999).

Lu et al. (2016) found that implementation of innovative technological tools such as Proactive Construction Management System (PCMS) and encouraging employees for other co-workers safety responsibility are more cost effective than safety supervisors for conducting inspections.

1.2. Research objectives

The main objective of this study is to develop an analytical-empirical model for the optimal allocation of resources (budget) in construction safety. This goal is achieved by finding the minimum amount of resources that should be allocated in preventive safety, i.e. all proactive acts aimed at providing safe work environment and protection of workers from occupational hazards in order to minimize the total project safety costs. Alongside the main objective, the costs of accidents are investigated in order to determine the relationship between direct and indirect costs for construction projects in Israel.

1.3. Research method

To achieve the research objectives and validate the model seeking for the optimal investment in safety, the research method is structured as follows:

1. definition and analysis of all the costs involved in residential construction work accidents distributed in direct costs (DC) and indirect costs (IC) by means of a critical literature review;
2. analysis of the findings of a field survey including 30 construction projects;
3. development of a probabilistic model using Monte Carlo simulation and analysis of the scenarios generated by the simulation;
4. recommendation of the optimal degree of safety investment and determination of the relationship between direct and indirect cost of accidents.

2. Costs of construction accidents

2.1. Direct and indirect costs

In construction, the costs of an accident are accounted as direct and indirect. In this study, direct and indirect costs of accidents are formulated in accordance with the following definitions.

According to Everett and Frank (1996), the direct costs of accidents can be defined as those actual, contractor cash flows that can be directly attributed to injuries and fatalities. These costs include:

- workers' compensation insurance to provide wage replacement and medical treatments during recovery time;
- public liability insurance against third-party injuries and damage to third-party property;
- property insurance to cover the damage of equipment and facilities.

Contrary to the direct costs, which are generally quantifiable with good accuracy, indirect costs are difficult to quantify precisely (Hinze and Appelgate, 1991) so they are often regarded as 'hidden' costs. Levitt et al. (1981) identified them as:

- costs due to loss of productivity of the crew and the injured worker;
- expenses for investigating the accident;
- training of the replacement employees;
- cleanup and repair;
- costs due to project time overrun.

Moreover, the share of indirect costs is usually much greater than the direct costs share.

It is widely supposed that most of the construction costs resulting from accidents are covered by insurance companies. In reality, only those that are considered to be direct costs are insured. Indirect costs such as: loss of earning days, temporary unavailability of workers, and any other cost not regarded as direct cost are not covered (Hinze and Appelgate, 1991).

2.2. Direct to indirect costs ratio

In the past, indirect costs were commonly determined by multiplying the direct costs by an indirect cost multiplier. This, according to Everett and Frank (1996), is actually the same as calculating the ratio between direct and indirect costs.