AN ECONOMETRIC EVALUATION FRAMEWORK FOR INVESTMENT IN CONSTRUCTION SAFETY

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A growing body of empirical research has been focused on the relationship between investment and return on safety in the construction industry. However, these previous studies mainly described the accidents occurrence in terms of actual numbers, which were based on the hypothesis that when there is an investment, there will be an effect on construction safety performance and hence the number of accidents will be reduced. In reality, investment on construction safety does not guarantee in reducing the actual numbers of accident occurring in a construction project. The occurrence of accidents sometimes is out of control and indiscipline and hence remains random. Hence it presents a gap between the existing theory and the actual practice which means there is a need to develop theoretical framework that can closely model the accidents' randomness. To fill the gap existed in the previous studies, this paper presents an econometric analysis framework for evaluating the effectiveness of safety investment in construction project. The fundamental assumption is that the investment on safety can only reduce the probability of accident and the number of accidents occurring will behave as a random number in a range with some distributions, or, statistically speaking, shift the distribution of accidents. Firstly, the distribution of construction accidents will be determined by an econometric model. Then the differences in cost with and without safety risk reduction and mitigation programme will be calculated as the benefits of the investment. Individual simulations have no certainty on whether there is benefit, but by doing sufficient numbers of simulations (e.g. 10,000 or more) the distribution of return on investment (ROI) will be acquired. Detail steps for implementing the framework is provided, the results of the econometric evaluation will be made as the expected ROI and its confidence interval, due to the random nature of ROI. The framework developed in this paper will be the base and instruction for future work including using actual project data to test and validate the framework and proposing optimized safety investment models.

Keywords: econometric evaluation, safety economics, safety investment, effectiveness, accident, injury.

INTRODUCTION

The construction industry has a reputation as one of the most unsafe industries due to the market fragmentation, complexity of construction sites, and high level of small sub-contractors, as well as high injury and incident rates (Haslam 2005; Zou *et al.* 2007; Gambatese *et al.* 2008). The costs of construction accident/incident are very expensive (Feng 2009). For example, from 2006-2007 in Australia, the cost of work-related injury and illness of construction industry bears 11% of the total costs, accounting for approx 6.3 billion and ranked as the third highest among all industries

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accounting for approx 6.3 billion and ranked as the third highest among all industries (ASCC 2009). High occurrence of accidents not only causes huge economic loss to the country and companies, but also brings human issues and reputation problems to the construction companies. To alleviate the serious safety problem, the Australian government has developed relevant guidelines and policies for safety risk reduction and mitigation (ASCC, 2002). Researchers have been focusing on indentifying and controlling safety risks in construction project (Gurcanli 2009; Lingard and Holmes 2001; Arezes and Miguel 2008; Fung and Tam *et al.* 2009). Safety investment and safety preparation programme has been taken as input for sustainable development in safety management (Rechenthin 2004), bringing company huge tangible and intangible benefits. While there is a great deal of knowledge regarding the safety management strategies of highly effective construction firms, little is known about the cost-effectiveness of these strategies (Hallowell 2010).

Several studies have attempted to analyse the cost-benefits of construction safety investment (Zou *et al.* 2010; Sun and Zou 2010; Feng 2009). However these studies were mainly based on the assumption of a direct cause-effect relationship between investment in safety and safety performance improvement, that says, if there is investment in to construction safety management, there will be sure an improvement of safety performance. The reality is however, no guarantee is given to the direct relationship described above. Which implicates that distribution will be much more appropriate for describing the actual occurrence of accidents. Thus, econometric theory, based upon the development of statistical methods for estimating economic relationships, and evaluating and implementing government and business policy, is introduced in this research to determine the distribution and behaviour of construction accidents. The difference between this research (i.e. presented in this paper) and the previous ones is to address this point by introducing a probability-simulation based econometric model for evaluating ROI in safety investment. The aim of this research is to develop an econometric theoretical framework to evaluate the effectiveness of safety investment in construction, based on a ROI model.

RETURN ON INVESTMENT MODELS

Several assessment tools have been proposed to measure the effectiveness and efficiency of safety risk prevention programme. For example, the 3P+I model (Teo and Ling 2006), the safety performance evaluation (SPE) framework (Ng *et al.* 2005), and the experience modification rate (EMR) (Hoonakker *et al.* 2002). However, the SPE framework is not accepted widely as the subjectiveness in the development of the weights and additional assumptions utilized in the computations of the weighted score average. Though the result of EMR analysis is relatively reliable, its formula is somewhat complex and different versions of calculation exist in practice. Thus in this paper ROI model is introduced to evaluate the effectiveness of safety investment.

ROI model is verified to be easy and typical in investment evaluation (Rohs 2006), Lately, it has also been used to evaluate the effectiveness of Safety Risk Management System in Construction (Zou *et al.* 2010). The most common ROI model is (Stone 2005).

$$ROI(\%) = \frac{Total\ Benefit - Cost}{Cost} = \frac{Net\ Benefit}{Cost}$$

In this research, to evaluate the effectiveness of construction safety investment, we can define the cost in the formula as the investment on safety risk reduction and mitigation programme. The benefit is the savings from the cost of accidents that could have happened. Based on the step-by-step approach proposed by Philips (2002), the process of implementing the ROI model to evaluate the effectiveness of safety investment in construction can be described as Figure 1.

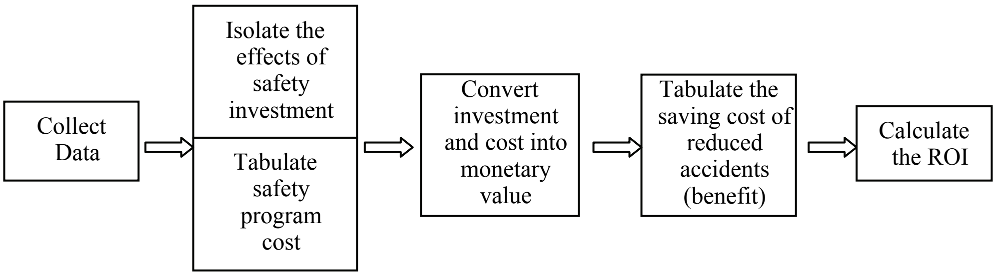

Figure 1: Process for ROI calculating in safety (adapted from Philips 2002)

Which should be noticed is that, the number of accidents will be performed as a distribution with probability. The distribution of construction accidents will be determined by an econometric model. Then the difference in cost with and without safety prevention programme will be calculated as the benefit of the investment. Individual simulations have no certainty on whether there is benefit or not in fact, but by doing massive amount of simulations the return on investment (ROI) will be found as a random number with distributions.

Cost of safety risk reduction and mitigation programme (i.e. safety investment)

Investments in safety risk reduction and mitigation programme
From the ROI model presented in previous section, the first step is to find out the cost of safety risk reduction and mitigation programme. That is to identify and classify the investment in construction projects safety. Investment in construction safety risk reduction and mitigation programme is not where a company generates net revenue but a place that generates profit by reducing the levels of safety risks and the possibility of losses. The components of safety investments can be classified into six main categories, which include: (Feng 2009)

- Safety staffing costs: The safety staffing costs include payment for on-site staffing costs and head office staffing regarding safety management.
- Safety training costs: Safety training costs is for conducting safety training courses or safety prevention programme.
- Safety equipment and facilities costs: The main physical safety investment is input on safety prevention equipments or facilities, which directly improve the working conditions.
- Costs of new technologies methods or tools for safety: Advanced technology or tools such as information system could improve the quality and efficiency of safety management (Cheung *et al.* 2004).
- Safety committee costs: Safety committee costs refer to time lost due to safety committee activities, such as meetings and inspections.
- Safety promotion and incentive costs: Include promotion costs and incentive costs for formatting and encouraging worker's behaviour.

Opportunity costs
Moreover, when doing investment decision, the opportunity costs may exist, for example, if the company invest the money other areas, such as advertising, organization management, schedule control, costs control and others. The opportunity costs are often complicated and hard to detect or calculate, it may get benefits in terms

of better reputation, high productivity, less resource wasting and shorter schedule. Opportunity costs are hard to identify or calculate, thus in this research, we will just considered the input or costs on safety investment when evaluating the ROI of safety risk reduction and mitigation programme.

Benefits from investment in safety risk reduction and mitigation programme

Safety can be both a tangible and intangible asset, if the company so chooses and the client values safety, an active safety programme can be sustainable competitive advantage (Rechenthin 2004). The most direct benefits may come from the reduction financial loss due to reduced accidents occurrence. For many years the safety profession has used an iceberg to describe the costs of accidents, which includes equipment damage, replacement employee, administrative costs, supervisor's time, production delays, and similar costs (Rechenthin 2004). Accompanied with the reduced accident frequency, the number of disturbance on production has decreased and the workers' productivity can be improved.

Besides the tangible benefits, actually, the hidden values within the intangible benefits play an increasingly important role in a new economy that is characterized by 'paradigm shifts'. However, it's difficult to calculate the exact values of these intangible benefits or turn them into monitory terms. Based on previous studies (Mossink 2002, Rechenthin2004, Muñiz 2009), The main benefits from safety investment can be listed in the following Figure 2.

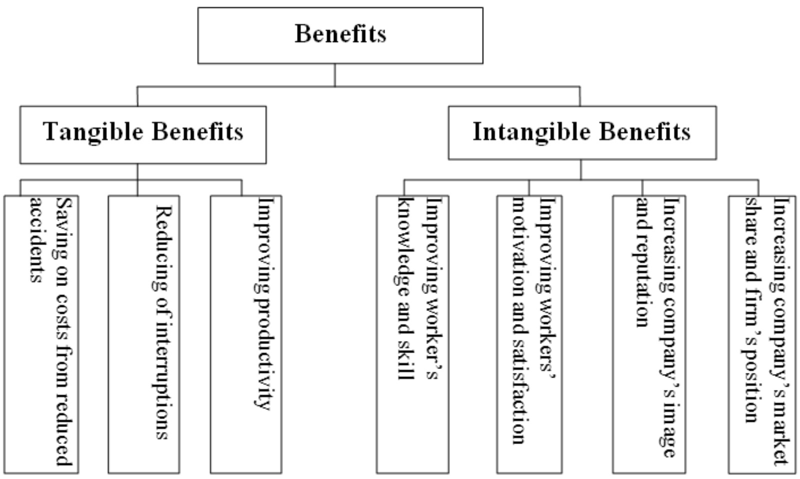

Figure 2 Components of benefits from safety investment in construction

From the extensive analysis ROI model of safety investment, we notice that the key step of the evaluation would be to find out the reduction of accidents occurring which are the results of the safety investment. Then two questions are faced when undergoing this step.

1. How to simulate the distribution of accidents? As mentioned in the introduction Section, investment on safety has no guarantee on reducing the actual number of accidents in reality, and then the number of accidents will act as a random number with some distributions.
2. How to identify and separate the effects of the safety investment from the others? Numerous factors besides safety investment which may have significant impact on accidents occurrence, including internal and external ones.

To solve with the two puzzles above, econometric theory and model, which is developed upon the statistics, is introduced in this paper.

PROPOSED ECONOMETRIC EVALUATION MODEL

Econometric theory

Econometrics is based upon the development of statistical methods for estimating economic relationships, testing economic theories, and evaluating and implementing government and business policies. Econometric analysis is concerned with the quantitative relationships between economic variables and it can provide an important input into manager's decision making. Typically econometrics differs from other aspects of management science in that it considers problems primarily, though not exclusively, from a background of economics rather than of other disciplines and behaviour is usually dealt with at higher level of data aggregation than the individual firm (Ball *et al.* 1974).

Econometric analysis is concerned with the quantitative relationships between economic variables and it can provide an important input into manager's decision making. Econometric is a good tool to analyse the relationship between variables and dependent variable. For example, Blinder and Esaki (1978) have examined the impact of cyclical changes in inflation and unemployment on the UK size distribution of income by some econometric tests. Canterbery (1996) used it to simulate the cost savings from nuclear regulatory reform. Based on an econometrics analysis, Dickerson at el (2000) developed an empirical model of the relationship between road traffic accidents and traffic flows.

There were also studies on econometric analysis in relation to safety. Borooah *et al.* (1998) investigated the determinants of workplace injuries using an econometric analysis based on injuries compensation data for Queensland. Friedman and Forst (2009) used econometrics to determine the cost of claims among construction workers. Econometrics, however, has not been used to measure the ROI of safety risk prevention, reduction and mitigation programme in the construction industry, thus this research will propose an econometrics model to measure the effectiveness of the investment in safety risk management (prevention, reduction and mitigation) programmes.

To answer Question 1 proposed above, the fundamental assumption of the econometric model is that the number of accidents occurring will behave as a random number with distributions and the investment on construction safety can only reduce the probability of accidents or, statistically speaking, shift the distribution of accidents. Thus, this model should describe the distribution of probabilities of accidents on the basis of variable causal factors.

LOGIT regression model

In econometric research, a LOGIT model is most commonly used in modelling probability. When conventional bi-variates statistical model could not elaborate the problem properly, multinomial Logit model has been applied in many studies. A multinomial Logit approach was proposed to analyse the determinants of worker's probability of dismissals, quits and layoffs in firms (Campbell III 1997), and to estimate the probabilities of a banking crisis (Demirgüç-Kunt 2000). In recent research, it has been used to find out the influence of different variables (such as age, gender, urban or rural residence, seasons and occupations on suicide probability) (Chuang *et al.* 2004). In this paper, a multivariate model is introduced to analyse the effects of safety investment and other variables on accidents occurring probability, by plotting the histogram of accidents and estimating its density function, the simulation of accidents can be conducted. The LOGIT model has the form as following,

$$P(y = 1|x_k) = \Lambda(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k)$$

$$where\ \Lambda(z) = \frac{\exp(z)}{[1+\exp(z)]}$$

x_k *are the independent variables which have effect on probability of accident occuring*

β_k *are the coefficients of the independent variables, and indicate the marginal effect of independent varibles*

From the formula above, the LOGIT model does transformation to its independent variable, keeps probability behaviour always between 0 and 1, rather than describes a linear relationship between dependent and independent variables, so it is appropriate to modelling the probability. By investigating the coefficient of investment on safety risk management programme, and plotting the histogram of No. of accidents happened with and without investment on safety risk management programme, and estimating its expression equation by different variables, the distribution of the accidents reduced can be estimated., The effectiveness of safety investment can be calculated using the formula.

Factors involved in construction accidents

Besides, the independent variable (factors) will be included in the right hand side of the LOGIT model. Ideally, it should have all information which has significant effects on the probability of accident occurrence. Of course, the different types of investment on safety risk management programme will be the significant factors, and the other elements from organization, society, worker, projects and so on are also considered and analysed. In this paper, based on previous studies, we select a series of variables into the LOGIT model (Listed in Table 1), thus in the evaluation system, the LOGIT econometrics model for analysing the effect of variables on accidents could be described as following.

$$\begin{aligned} \mathrm{P(Y = 1|x)} = \Lambda\Big[\alpha &+ (\beta_1\,\mathrm{SS} + \beta_2\,\mathrm{ST} + \beta_3\,\mathrm{SEF} + \beta_4\,\mathrm{STT} + \beta_5\,\mathrm{SC} + \beta_6\,\mathrm{SPI}\Big) \\ &+ \Big(\gamma_1\,\mathrm{AW} + \gamma_2\,\mathrm{EW} + \gamma_3\,\mathrm{GW} + \gamma_4\,\mathrm{NW}\Big) + \Big(\delta_1\,\mathrm{FS} + \delta_2\,\mathrm{SW}\Big) \\ &+ \Big(\varepsilon_1\,\mathrm{SC} + \varepsilon_2\,\mathrm{WE} + \varepsilon_3\,\mathrm{SL}\Big) + \Big(\eta_1\,\mathrm{PZ} + \eta_2\,\mathrm{CS}\Big) + (\theta_1\,\mathrm{GP} + \theta_2\,\mathrm{LC})] \end{aligned}$$

$$\text{where } \Lambda(\mathrm{z}) = \frac{\exp(\mathrm{z})}{[1+\exp(\mathrm{z})]}$$

After LOGIT regression, the coefficient of each factor will tell how much effect of each variable on accident occurrence. The marginal effect of each categories of safety spending according to different types of accidents can be represented by its coefficient. For example, the marginal effect of safety staff cost can be calculated by β_1. The marginal effect of other factors can be determined in the same manner, and hence the most efficient safety spending can be determined by its sensitivity. Furthermore, by plotting the histogram of the number of accidents happened with and without some types of safety investment, the probability density function and cumulative probability function of accident can be also estimated. And once the probability density function and cumulative probability function of accidents are determined, according to ROI formula, the effectiveness of the safety investment will be calculated. Through the coefficient of each variable, the factor which has the most significant impact on accidents can be determined and the information could be useful for decision makers on safety investment in construction firms.

Table 1: Factors involved in construction accidents

Categories	Factors Involved	Sources	Discussion
Safety Investment (SI)	Safety staffing costs (SS)	Heath 1982; Laufer 1987;	Include on-site staffing costs and head office staffing costs
	Safety training costs (ST)	Brody *et al.* 1990;	Include formal safety training courses and In-house safety training.
	Safety equipment and facilities costs (SEF)	Tang *et al.* 1997; Hinze and	Include personal protective equipment and safety facilities (material and machinery).
	costs of new technologies methods or tools for safety(STT)	Cambatese 2003; Feng 2009	Include costs on new technologies methods or tools
	Safety committee costs (SCC)		Include safety costs on meeting and inspection
	Safety Promotion and Inventive costs (SPI)		Include promotion and inventive costs
Workers and Work Team (WW)	Average age of workers (AW)	Mcvittie 1997;	Average age of labours
	Experience(Skills) of workers (EW)	Borooah 1998; Sawacha *et al.*	Average working years of labours
	Gender of workers (GW)	1999;	Gender balance condition of workers
	Number of workers on site (NW)	Hinze and Cambatese	Indicate the size of work team
Organization (OG)	Firm size(FS)	2003; Kines *et al.*	Can be described by number of employees
	Supervision on workers(SW)	2003; Siu *et al.*	Number of supervisors in the organization
Workplace (WP)	Site condition (SC)	2003;	Weather and tidy condition of site
	Working environment(WE)	Fabiano *et al.*	Include lighting,noise, cold, wet, hot
	Site layout/space(SL)	2004;	Site space
Construction (CO)	Projects size(PZ)	Haslam *et al.* 2005;	Size and type of project, could be described by contract price
	Construction schedule(CS)	Aksorn *et al.* 2008;	Indicate whether the schedule tight or loose, described by the contract period
Public Policy (PP)	Government policy(GP)	Cheng *et al.* 2010	Government expenditure on public safety
	Legal condition(LC)		Compensation policy

PROPOSED ECONOMETRIC EVALUATION FRAMEWORK

At last, based on the above review of ROI and econometrics theories, the two are combined to establish a framework to evaluate effectiveness of safety investment, as shown in Figure 3.

CONCLUSION

Construction worksites are one of the most dangerous places worldwide leading to high incidence and accidents rates. Proving the effectiveness of safety investment is quite urgent for construction companies. This paper reviewed previous studies related to safety investment and construction accidents, based on the ROI model developed, identified the benefits of safety investment and costs of safety investment. It also innovatively introduced the econometric theory for evaluating the effectiveness of construction safety investment which was believed to be the first of its kind in construction research. A multivariate LOGIT regression model is explored to find out the determinants of accidents occurring in construction projects. The framework of the econometric evaluation of effectiveness of safety investment is given in the last part of the paper, which will be the instruction of future work.

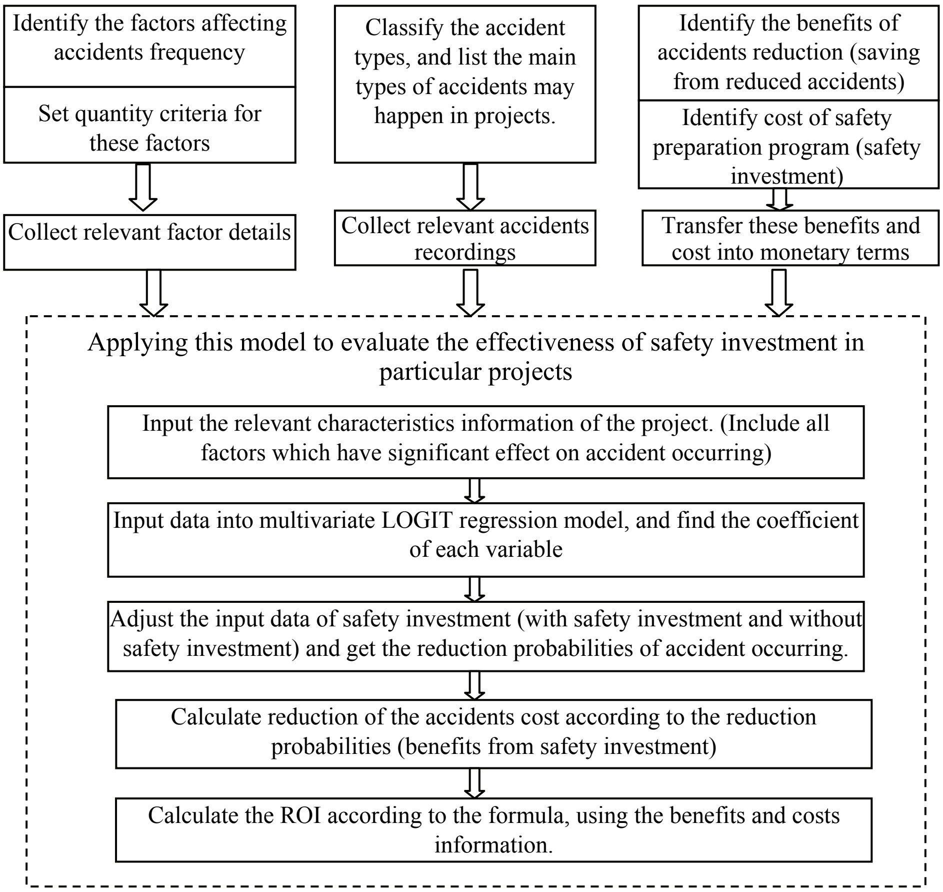

Figure 3 Econometric evaluation framework for effectiveness of safety investment

This study is the first step on evaluation of effectiveness of safety investment of the whole research, the work following will be data collection and simulation. Cooperation with construction companies and case study will be conducted in future work. The potential implication of this research includes providing a set of new theories and models grounded by econometrics for both researchers and industry practitioners to advance their knowledge and practice and helping the construction industry to understand the importance and quantifying the effectiveness of safety risk management programme, thus will lead to reduction of incidents and fatalities.

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