SPECIALIZED FIELD: CONSTRUCTION MANAGEMENT

A METHOD TO ESTIMATE OCCUPATIONAL HEALTH AND SAFETY COSTS IN CONSTRUCTION PROJECTS

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Abstract: This paper presents the results of a research project carried out in Spain that aims to develop a method that let employers to assess, during the design phase, the occupational health and safety costs of a specific construction project. This method classifies costs in four categories: insurance costs, prevention costs, accident costs, and recovery of costs. Labor accident data were obtained from 1990 to 2007 for the entire Spanish construction industry, and these data were subsequently homogenized and exploited. A mathematical model was created for computing each cost category. This method allows employers and project managers to estimate aprioristically the cost incurred as a result of occupational health and safety during the project, based on tangible values such as the construction project budget or the work schedule, as well as statistical data. An application to this method in a case study illustrated that the occupational health and safety costs for that construction project came to approximately 5% of the total cost of the budget.

Keywords: accident; construction; cost; health and safety; method

1. INTRODUCTION

The construction sector has an accident rate much higher than the average in other sectors of economic activity; this is the scenario for most developed countries (Levitt et al., 1981; Lee, 2004; ILO, 2005; Waehrer et al., 2007). Apart from loss of life, injury, and occupational illnesses, workplace accidents also generate high economic costs (Lee, 2003). Many of these costs are directly absorbed by the employer, which amounts to a reduction in the profits of the construction project (Laufer, 1987; Levitt and Samelson, 1993; Everett and Frank, 1996; Rubio et al., 2008).

Various authors highlight the important economic losses generated by accidents at the construction work site (Helander, 1980; Everett and Frank, 1996; Rubio et al., 2005; Waehrer et al., 2007). Evidently, if employers had a tool that allowed them to calculate aprioristically the occupation health and safety costs during the design phase of a construction project, they could try to reduce these costs later at the construction site by improving procedures and increasing the quantity and quality of accident prevention measures.

It is in the design phase of the construction process when risk prevention is most effective, as has been pointed out by certain authors (Gibb, 2004; Gambatese, 2008). Consequently, any tool that can be developed previous to the execution of the construction works can contribute to the reduction of workplace accidents and the improvement of safety conditions for the workers (Lee et al., 2011). Thus, the main objective of this research is to design a method that would permit employers to estimate, during the design phase, the occupational health and safety costs that might occur in the execution phase of a construction project at the work site.

This paper is organized in five main sections. Section two describes the literature review. Section three summarizes the research design and data sources used. Section four defines the components necessary to estimate the cost of occupational health and safety during the design phase of a construction project, and how they can be calculated. The article wraps up with a case study of how the model can be applied. Finally, the last section presents the most relevant conclusions.

2. LITERATURE BACKGROUND

Heinrich was the first author that differentiated between causes and consequences of occupational accidents (Heinrich, 1927 and 1931). He made important contributions on accident costs, causes of accidents and accident mechanisms (Swuste et al., 2010). According to Heinrich (1927 and 1931), the hidden costs of accidents are four times higher than costs on compensation, generating the metaphor of the iceberg. Hence, he proposed the first calculation method for accident costs, making the costs of accidents manageable for insurance companies (Swuste et al., 2010). Later on, he also analyzed these costs applied to the construction industry (Heinrich, 1938).

Four decades later (in 1979) the Business Roundtable, an organization representing the biggest US corporations, commissioned a working group to examine the occupational accidents costs in the construction industry. The analysis of the data and the study methods were developed by a group of researchers at Stanford University and summarized in a report by Levitt et al. (1981). This study was used as a theoretical basis for calculating the percentage of project costs attributable to occupational accidents. These costs were divided into direct (insurable) and indirect costs. These indirect costs included: loss of productivity, disruption of schedules, administrative time for investigations and reports, training of replacement personnel, wages paid to the injured workers and others for time not worked, cleanup and repair, adverse publicity, third-party liability claims, and equipment damage. This report showed that the cost of accidents was 6.5% of the total construction costs. Further enhancement of this method was thoroughly explained in Levitt and Samelson (1993). Many of the later methodological proposals for calculating occupational accidents costs were based on these studies with minor adjustments, not only for the construction industry, but also for other sectors such as forestry (Klen, 1989) or furniture (Soderqviest et al., 1990).

Leopold and Leonard (1987) analyzed accident costs from the point of view of the employer, also setting apart direct and indirect costs. For these authors, indirect costs are those that do not involve the employer in additional payments whatsoever, but impose an additional charge on other costs.

Using a survey with several British construction firms, they detected that indirect costs were associated to labor time.

Brody et al. (1990), based on a previous proposal by Andreoni (1986), divided the occupational health and safety costs in three basic components: prevention, insurance and the hazard; later in the advance of their method, they grouped them into indirect and direct costs. These authors also proposed a graphical method for calculating hidden or indirect costs of accidents that were usually underestimated by the employer, including: wage costs, material damage, administrator's time, production losses, and intangible costs.

Miller and Galbraith (1995) presented five cost categories, usually used in the US national accounting system: medical and emergency services; wage and household work-lost wages, fringe benefits, housework, and other household services; administrative and legal costs-costs of accident investigation and litigation; workplace disruption-overtime pay, loss of special skills, and productivity losses by supervisors and colleagues, and recruitment and training costs; and quality of life. Everett and Frank (1996) divided the cost of occupational accidents in the former two categories; they considered the insurance as the direct cost, including the worker's compensation, the public liability, and the property insurance, whereas indirect costs embraced the same as in Levitt et al. (1981). Everett and Frank (1996) compared their method with Levitt et al.'s (1981), obtaining that the cost of accidents had increased to 7.9% of the total construction costs. The research of Waehrer et al. (2007) was summarized in a cost model that comprised direct and indirect costs, plus the estimate of the quality of life costs due to the injury, as presented previously by Miller and Galbraith (1995).

Rikhardsson and Impgaard (2004) took a different approach. First, they considered six kind of groups: absence of the injured employee, communication, administration, prevention, operation disturbance (e.g. training of replacements, revenue loss, coworkers overtime, and production reductions), and fines and gifts to the injured employee. Second, they used activity based costing as an evaluation tool in order to obtain the standard costs of occupational accidents, differentiating three kind of costs: variable, fixed and disturbance costs; these costs depend on the specific accident and the role, tasks and competencies of the injured person. Standard costs were used to assess the financial impact of accidents in a company, just multiplying them by the number of accidents occurred or expected.

Summarizing, the costs of occupational accidents, and even the costs of occupational health and safety, are formulated by most of the authors in terms of direct and indirect costs, generally as a ratio. This relationship varies from author to author, depending on several factors such as the research method, sector under analysis, national insurance systems, and even the own definition of direct and indirect costs. Although some researchers pointed out this weakness in the past (Klen, 1989; Soderqviest et al., 1990), most of the current studies still concur with this path.

3. RESEARCH DESIGN

The method presented in this paper follows the line of thought initiated by Andreoni (1986) and pursued by Brody et al. (1990). Occupational health and safety costs can be considered as the sum of three components: prevention, insurance and accidents. It pretends to calculate, not only the ex-post costs (accidents), but also the ex-ante costs (insurance and prevention) taken on by the employer only; long-term costs to the victim and to society, as well as loss of quality of life costs and other subjective costs are explicitly excluded, as already done by other researchers in the past, such as Leopold and Leonard (1987), for instance.

The proposed method, based on the former assumptions, can be characterized as follows:

- It is adapted to the peculiar characteristics of the construction industry.
- It is aprioristic in the sense that it pretends to know, during the design phase, the occupation health and safety costs of the execution of the construction project, thus the prevention costs considered are only a rough figure.
- It uses real data from the Spanish construction industry to make the calculations.
- It details each of the specific calculations to be done, whereas other models only propose percentages of indirect costs or give a general approach.
- It adds up a fourth component, named “recovery of costs”, that considers the costs that are recovered by the employer later in the process.

This method is adapted to the characteristics of the Spanish regulations. In Spain the Social Insurance Institute (public institution dependent on the Ministry of Employment and Social Affairs), jointly with the Mutual of Work Accidents chosen by the employer, insures all employees for occupational accidents and diseases. This means that a Spanish employer has no expenses regarding rehabilitation and medicine because they are already included in the insurance costs. The Spanish system differs from the United States system in this issue: the latter relies on private insurance companies. An in-depth explanation of the occupational health and safety system in Spain can be found in Sese et al. (2002); it is comparable to other European countries, based on similar social security systems as well as the global framework provided by European Union Directives.

Table 1 registers the occupational health and safety cost components relevant to this study, and classifies them in the four previously mentioned categories, like so:

- Insurance costs are the amount that employers legally obliged to pay by law so that workers will be covered in case of accident or occupational illness. The amount to be paid depends on the job category of the worker.
- Prevention costs are the result of all the factors that employers must take into account in order to comply with the workplace safety regulations currently in force.
- Accident costs entail the consumption of economic resources and materials, depending on the severity of the accident; evidently, more serious accidents have higher costs. For calculation purposes, economic sanctions, fines, and surcharges are not included since it is assumed that the project developer or employer had complied with all safety regulations and specifications; this assumption is in consonance with the Spanish law.
- Recovery of costs refers to the amount that the employer gets back because of welfare payments to the injured worker after the second day of medical leave, as regulated by the Spanish national social security system.

<TABLE 1>

Within the context of this research project, the Spanish Ministry of Employment and Social Affairs (MTAS) provided primary data regarding occupational accidents with at least one day of medical leave in Spain between 1990 and 2007. This information was obtained directly from the official occupational accident reports; according to the Spanish law, a medical report must be filled out by the physician, and later on an official report based on the first one must be also submitted to the labor authorities whenever any worker suffers an injury at the work site. Accidents are classified in this way:

- Minor accidents have medical leave (more than 1 day), but they do no cause permanent disability.

- Serious and very serious accidents cause permanent disability to the worker; the differentiation between them depends on the physician report only.

- Fatal accidents (or deaths) are the ones which lead to the death of a victim within eighteen months of the accident.

The data facilitated by the MTAS was composed of over 15 million records, grouped according to their characteristics:

- 1990-2002: 108 digits per record and 31 data fields.

- 2003-2007: 164 digits per record and 58 data fields.

However, in order to exploit these data, all of the information had to be processed to begin with (Carvajal, 2009). Firstly, the sequential data files (.txt) were converted to a format compatible with SQL Server 2000. Then the data fields and the figures of the original database were homogenized; generally the two groups of data files (1990-2002 and 2003-2007) did not contain the same number of records and digits, and codes and descriptions were different as well. Additional tables were produced for each one of the variables in order to unify both groups of data, complementing digits and records if necessary. For instance, the data field "description of the injury" contained 2 digits, 20 records and 12 different alternative descriptions for the 1990-2002 series, whereas it included 3 digits, 48 records and 15 descriptions for the 2003-2007 series; in this case, the complementary table contained the same digits, records and descriptions as the 2003-2007 data field. Furthermore, those records whose volume of information was incomplete or wrong, within their most significant variables, were eliminated.

Table 2 illustrates the temporal evolution of exposure time, number of accidents, and days of medical leave; data is obtained from the exploitation of the database created from the primary data provided by the MTAS, corresponding to 1990-2007. Table 3 shows the percentages and distribution of occupational accidents, according to accident type. In that table, each accident type has a code that is used for future reference; this codification summarize the MTAS classification criteria, which has not been homogeneous through time (Carvajal, 2009).

<TABLE 2>

<TABLE 3>

4. CALCULATION OF COSTS

4.1. Insurance costs

Insurance costs (*IC*) depend on two variables: base salary (*BS*) and professional contingencies (*CN*). In Spain, these figures are published each year by official sources, and they depend on the job category and the contribution group (MTAS, 2008). The abbreviations used henceforth are summarized in the Appendix at the end of the paper.

Professional contingencies (*CN*) are payments made by the employer to cover workplace accidents and occupational illnesses. In Spain, values applicable to the construction sector are 3.95% for temporary incapacity and 3.50% for permanent incapacity or death (MTAS, 2008). They are generally a percentage of the base salary. Consequently, insurance costs can be expressed as an increase in the base salary, depending on professional contingencies (Eq. 1).

$IC = (1+CN/100) * BS = 0.0745 * BS$ (Eq. 1)

4.2. Prevention costs

Prevention costs (*PC*) depend on the budget of the construction project (*BC)* and on the percentage of the budget invested in prevention (β). The budget of the construction project is obtained directly from the design phase. For this reason, the project developer knows it before the execution phase has begun.

The percentage invested in risk prevention (β) was estimated by analyzing 173 health and safety plans from a sample of randomly selected construction projects. The mean value of the prevention costs came to 1.54% of the total budget of the project. Consequently, prevention costs were calculated (see Eq. 2) by multiplying the construction project budget by the risk prevention variable (β).

$PC = \beta * BC$ (Eq. 2)

4.3. Accident costs

The first step in obtaining accident costs for a construction project entails ascertaining the frequency index (*FI*). The *FI* is calculated by measuring the accidents per cause in a year per million hours worked. Accordingly, in our study, the *FI* was calculated for each of the eight accident types defined and codified in Table 3. Another factor taken into account was the severity of the accidents: minor, serious, very serious, and deaths (as defined by the physician in the medical report).

The estimate of *FI* was based on the ratio between the number of accidents (*NA*) during the time periods considered (see Tables 4, 5, 6 and 7) and the total number of man-hours (*NH*) in a period of time per million hours worked (see Table 2); both values, *NA* and *NH*, were obtained for the entire Spanish construction industry exploiting primary data from MTAS. Due to lack of space, it is not possible to show the complete set of results, but they can be easily obtained by applying Eq. 3.

$FI_{jk} = NA_{jk} * NH * 10^{-6}$ (Eq. 3) where j = accident type; k = severity of accident

<TABLE 4>

<TABLE 5>

<TABLE 6>

<TABLE 7>

Once obtained, FI is then multiplied by the exposure time at the construction site (EX). To be able to calculate EX, the detailed construction schedule must be known beforehand. Given the importance of this parameter, this construction work schedule has to be well planned. Each task should be defined in terms of the worker who must perform it and the number of hours scheduled to complete it (HS), as expressed in Eq. 4.

$EX = \sum_{im} HS_{im}$ (Eq. 4)

where i = worker; m = construction task

Nevertheless, in general, it is difficult to know a priori the exposure time at the construction site (EX). Thus, calculations can be simplified, losing accuracy, by applying the ratio of labor (α) regarding the construction budget (BC) and dividing by the average hourly cost (CH), as shown in Eq. 5, in order to obtain the hours employed by the workforce at the site. For instance, in 2007 at Spain, an average of 37.7% of the budget in construction projects is due to labor, while the average gross hourly cost is 11.85 €/h (Ministerio de Fomento, 2008).

$EX = \alpha * BC / CH$ (Eq. 5)

Anyway, multiplying the exposure time for the construction project (EX) by the estimated frequency indices (FI), the expected number of accidents during the construction project (NW) is obtained for each accident type (Eq. 6).

$NW_{jk} = EX * FI_{jk}$ (Eq. 6)

where j = accident type; k = severity of accident

The cost of the accident per type (CT) comprises the calculation of the cost of all accident variables considering the type of accident. It also includes those that are not directly linked to the production process, but which are also affected by the accident. These variables are the following: time lost; time spent by others on the accident; cost of materials; transfer and substitution costs; and loss of production and business. Each of these variables is defined in the following paragraphs.

The cost of the time lost (TL) takes into account not only the worker who suffered the accident, but also the other workers who were forced to stop working because of the accident. This work stoppage can occur for different reasons (e.g. to help the injured worker, to discontinue the production process, to satisfy curiosity, etc.). Whatever the reason, this all amounts to less production time, which signifies time that the company is paying for without receiving any work in exchange. This value is obtained by multiplying the worker's cost per hour (CH) by the time taken up by the accident. This time is composed of two values:

Time lost by the injured worker (*HA*): A loss of four hours was estimated for each injured worker and one hour for each affected co-worker (Aranguren et al., 2004). These values were taken as a standard reference for serious accidents. For minor accidents and very serious accidents no value was found in the literature; thus, the authors estimated a 50% lower and a 50% higher value than the one proposed by Aranguren et al. (2004).

Time lost by other workers because of the accident (*HO*): The references for this value were the estimates of the Spanish National Institute for Work Safety and Hygiene (Gil and Pujol, 2000), who proposed four lost hours. As in the previous case, these standard values were adopted for serious accidents. For minor accidents, the estimate was 50% lower than this value, and for very serious accidents, the estimate was 50% higher than this value.

The calculation is expressed in Eq. 7.

$TL_k = CH * (HA_k + HO_k)$ (Eq. 7)

where k = severity of accident

It is also necessary to consider the cost of the time spent by others on accident-related activities even if this time is not related to the production process (*TR*). This includes the investigation of the accident by middle management or the risk prevention service, administrative work as a consequence of the accident, and the time spent on the accident by the senior executives, among others. It also takes into account the time taken up by lawsuits and court trials. The following section specifies the values for each variable (Eq. 8), based on Aranguren et al. (2004):

- Time spent on accident-related activities by senior management (*HM*): Two hours were estimated for each senior executive affected.

- Time spent on accident-related activities by administrative personnel (*HD*): Depending on the severity of the accident, for minor accidents, half a day was estimated for minor accidents, one day for serious accidents, and a day and half for very serious accidents.

- Time spent in investigating the accident (*HI*): Depending on the severity of the accident, five work days were estimated for minor accidents, ten work days for serious accidents, and fifteen days for very serious accidents.

- Costs of materials: This variable includes the damage suffered by the buildings or construction installations, production equipment (e.g. machinery, tools, etc.), raw materials, and the finished or semi-transformed products. To estimate this value, it was necessary to consider if the repairs were performed by company employees or by an external service. In the first case, the cost obtained depends on the number of hours used (*HH*) and the cost per hour (*CH*). In the second case, the value only depends on the subcontracting invoices and external suppliers (*ES*) who made the repairs.

$TR_{jk} = CH * (HM_k + HD_k + HI_k + HH_{jk}) + ES_{jk}$ (Eq. 8)

where j = accident type; k = severity of accident

The estimate of the transfer and substitution costs (*SC*) was based on the days of medical leave (*DL*), daily gross salary (*GS*), and the hospital transfer expenses of the injured worker (*TE*). The data pertaining to days of medical leave came from Table 8. The hospital transfer refers to the cost of the ambulance or the vehicle used to transport the injured worker. This cost was assumed to be constant for all accidents, and amounts to the estimated cost of ambulance transfer. Minor accidents were not included since it was assumed that they would not require this service. This is stated in Eq. 9.

$SC_{jk} = (GS * DL_{jk}) + TE_k$ (Eq. 9)

where j = accident type; k = severity of the accident

<TABLE 8>

Finally, the loss of production or business (*LP*) refers to the profits not obtained by the company as a consequence of the accident and the temporary partial or total stoppage of its production system (*SP*) and the increase in costs as a result of measures to maintain production at the same level. This is the case of overtime hours (*OH*) and the hiring of a replacement or substitute, depending on the days of medical leave (*DL*) and the gross salary (*GS*). This is specified in Eq. 10.

$LP_{jk} = SP_{jk} + (CH * OH_{jk}) + (GS * DL_{jk})$ (Eq. 10)

where j = accident type; k = severity of accident

Table 9 shows the model of the accident cost calculation record designed as a result of this study for each type of workplace accident. This record codifies the concept; includes the entry data used for the cost calculations, depending on the severity of the accident; and finally facilitates the results. The results are the sum of all of the previously calculated variables showing the cost of accidents per type (*CT*) in Eq. 11. Regarding the cost of materials and the loss of production, the data entered in the table are the mean values of a sample of 21 serious accidents, to which the authors had access. The values corresponding to minor accidents were assumed to be zero, whereas those corresponding to very serious accidents were considered to be double of those of serious accidents.

$CT_{jk} = TL_{ik} + TR_{jk} + SC_{jk} + LP_{jk}$ (Eq. 11)

where j = accident type; k = severity of the accident

<TABLE 9>

Table 10 summarizes the total costs according to the type and severity of the accident; the cost of fatal accidents (deaths) is independent of the type. Applying these values to the expected number of accidents during the execution of the construction project (*NW*), the cost of the expected accidents at the work site (*CW*) is obtained, as formulated in Eq. 12.

$CW_{jk} = NW_{jk} * CT_{jk}$ (Eq. 12)

where j = accident type; k = severity of the accident

<TABLE 10>

4.4. Recovery of costs

The costs due to the social benefits or compensation paid to the injured worker by the Spanish social security system can be partially recovered, according to law. The percentage of recovery is 75%, and it is calculated from the day after the first day of medical leave. For computing purposes, it is estimated as the gross daily salary (*GS*) of an average worker in the construction work, affected by the total number of days of medical leave (*DL*), minus one day, obtained from Table 8. They are multiplied by the expected number of accidents at the construction site (*NW*), calculated according to Eq. 6. The final formula for calculation of recovery costs is shown in Eq. 13.

$RC_{jk} = 0.75 * GS * (DL_{jk}-1) * NW_{jk} = 0.75 * GS * EX * NH * 10^{-6} * (DL_{jk}-1) * NA_{jk}$ (Eq. 13)

where j = accident type; k = severity of the accident

4.5. Mathematical model

The previous sub-sections led to the elaboration of the mathematical model proposed in Eq. 14. Each of the four cost categories is separated by brackets. After the first three (insurance, prevention and accident costs) are added, the last (recovery of costs) is subtracted from this sum.

$CC=[0.0745 * BS]+[\beta * BC]+ [EX * NH * 10^{-6} * \sum_{jk} NA_{jk} * CT_{jk}]-$

$[0.75 * GS * EX * NH * 10^{-6} * \sum_{jk}(DL_{jk}-1) * NA_{jk}]$ (Eq. 14)

where j = accident type; k = severity of the accident

5. CASE STUDY

The method described in the previous section can be applied to a case study. Let us consider a building project with a budget of 20,000,000 €. Before beginning the construction works, the project manager scheduled all of the work phases in great detail, including the human resources needed in each phase. This exhaustive planning made it possible to calculate the exposure time (500,000 hours) and the base salary for the whole workforce (7,000,000 €).

The insurance costs are obtained by multiplying the base salary (7,000,000 €) and professional contingencies (7.45% in the case of Spain) as stated in Eq. 1: $IC = 0.0745 * BS = 521{,}500.00$ €.

The prevention cost budgeted for this project is 1.50% of the total, then prevention costs (Eq. 2) amount to the following: $PC = 0.0150 * 20{,}000{,}000 = 300{,}000.00$ €.

Accident costs (*CW*) are obtained by multiplying the number of accidents expected at the construction site (*NW*) and the cost of each accident (*CT*). *NW* is calculated by multiplying the exposure time (500,000 h), the total number of accidents (Tables 4, 5, 6, and 7), and the total number of hours worked per million (Table 2). The results (*NW*) are shown in Table 11.

<TABLE 11>

The total cost per type of accident (*CT*) is displayed in Table 10. When Table 10 is combined with Table 11, the expected cost of the accidents at the construction site (*CW*) is obtained (see Table 12).

Adding up every cost per accident type and severity, the total cost of the accidents at the construction site is achieved: *CW = 186,681.03 €*.

<TABLE 12>

The recovery of costs is calculated by multiplying the 75% of the gross daily salary of an average worker in the construction project (94.80 €), the total days of medical leave (Table 8), minus one, and the expected number of accidents (Table 11), as specified in Eq. 12. The results are exhibited in Table 13. The corresponding sum gives the total recovery of costs: *RC = 57,182.07 €*.

<TABLE 13>

Finally, the total cost is obtained by adding the first three categories of costs and subtracting the last category: *CC = 521,500.00 + 300,000.00 + 186,681.03 – 57,182.07 = 950,998.96 €*. This value is approximately 5% of the total cost of the construction works.

As stated in the Literature Background, previous researchers estimated that occupational health and safety costs for a construction project were 6.5% (Levitt et al., 1981) and 7.9% (Everett and Frank, 1996) of the total cost of the construction project. These figures are higher than the one obtained in this research. However, the work of Levitt et al. (1981) and Everett and Frank (1996) can be compared because both teams used basically the same method (in fact the latter is an update and improvement of the former) and are located within the same context: the United States insurance system. The research explained in this paper is based on a governmental supported social security system, as implemented in Europe and other parts of the world.

6. CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

This paper proposes an innovative method to calculate occupational health and safety costs in construction projects. It is based on a theoretical approach that classifies these costs in three basic categories: insurance costs, prevention costs, and accident costs. A method of estimating the variables that make up each group of costs is proposed. It provides a mathematical formulation for the calculation of the different types of cost that intervene in occupational health and safety.

There are many factors that justify the design of a model that computes occupational health and safety costs in construction projects. However, the main reason for such a method is that employers realize, using this method a priori at the design phase, the magnitude of occupational health and safety costs and, consequently, they can visualize the importance of improving prevention measures in the construction project. Moreover, the project manager can estimate aprioristically the cost incurred as a result of occupational health and safety during the project, based on tangible values such as the construction project budget or the work schedule (number of workers and exposure time), as well as statistical data.

This paper presents a case study in which the health and safety costs for the construction project come to approximately 5% of the total cost of the budget. This value is about three times the average investment in prevention. As commented previously, other authors have found larger percentages (between 6 and 8%), based on the United States insurance system. Nonetheless, the method presented in this paper is based on a European social security system, and cannot be compared to the U.S. system. Furthermore, the insurance costs (IC) are required by the Spanish legislation and set for socio-political reasons. Therefore, it can be inferred that these insurance costs are underestimated and they are subsidized by the Government. This approach does not help to reduce the accidents because there is no apparent economic savings for the companies, such as the reduction of the insurance premium in the U.S. system.

The model still has a major limitation: If the expenditure in prevention increases, reducing the number of workers exposed to risks and substituting the most dangerous construction tasks for safer ones, the number of accidents (and their costs) does not vary. That conclusion does not seem reasonable, and it is reached because of the rigid relationship between prevention costs at the site (β, measured in the model as a percentage of the total budget of the project) and the costs of the expected accidents at the work site (CW). Designing a reliable correlation between prevention costs invested and accidents occurred at the construction site is not an easy work. Multiple case studies are needed in order to obtain reliable data to propose such a link; later on this correlation must be validated by additional data.

In its current form, the model is not sensitive to project type or other project characteristics. Other questions may arise in parallel to this research: Is the prevention cost proposed at the design phase actually spent for this purpose during the construction works? How this method could vary from country to country (basically due to the insurance costs)? Solving these questions requires additional research to build a solid method applicable to any construction site in any country. The authors are conscious of these limitations and are already working on it. Furthermore, the authors are replicating this research in Colombia, as a first step to compare different systems worldwide.

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APPENDIX: ABBREVIATIONS

<TABLE 14>

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Table 1

Category	Component
Insurance costs	Insurance contribution payments
Prevention costs	Individual protection elements
	Collective protection elements
	Safety and control systems for machinery and equipment
	Company medical service and first aid supplies
	Prevention service (of the company itself or another service provider)
Accident costs	Time lost by the injured worker
	Time lost by other workers because of the accident
	Costs of materials
	Hospital transfer expenses (ambulance or other vehicle)
	Accident management
	Investigation of the accident
	Recovery of production
	Substitution of injured worker
	Loss of business
	Loss of commercial image
	Labor conflicts
Recovery of costs	Recovery of insurance contribution payments

Table 1: Categories of costs and their components (developed by the authors)

Table 2

	Exposure time / 1000	Nº of accidents	Medical leave days
1990	1,905,480.9	141,941	3,551,932
1991	1,967,662.0	143,067	3,224,764
1992	1,856,419.4	119,285	2,720,884
1993	1,652,606.4	105,122	2,985,375
1994	1,717,923.4	112,497	2,793,953
1995	1,793,888.0	131,217	3,249,493
1996	1,914,141.1	137,592	3,568,644
1997	1,977,256.1	149,718	3,545,646
1998	2,187,022.2	181,980	4,148,497
1999	2,481,276.0	229,048	5,339,215
2000	2,633,350.5	250,768	5,741,553
2001	2,873,046.5	256,397	5,934,820
2002	2,928,466.3	256,589	5,961,984
2003	3,070,394.9	231,139	5,364,382
2004	3,335,025.8	224,440	4,831,552
2005	3,448,126.5	239,028	5,258,616
2006	3,716,792.0	250,624	5,438,541
2007	3,958,797.2	250,579	5,462,622
Total	45,417,675.3	3,410,846	79,122,473
Mean	2,523,204.2	189,491	4,395,693

Table 2: Temporal evolution of exposure time, number of accidents, and days of medical leave for the Spanish construction industry (developed by the authors based on MTAS primary data)

Table 3

TYPE OF ACCIDENT	CODE	%
Falls from heights	Ac01	13.09%
Slips and trips	Ac02	30.88%
Electrocution	Ac03	2.55%
Collision with or getting hit by an object	Ac04	42.45%
Entrapment	Ac05	4.45%
Lifting (over-strain)	Ac06	33.71%
Living things	Ac07	0.61%
Heart attack	Ac08	0.15%
Deaths		0.21%
Total		100.00%

Table 3: Accident types (developed by the authors based on MTAS primary data)

Table 4

MINOR	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08	TOTAL
1990	11,970	51,719	1,288	49,847	5,744	17,396	619	--	138,583
1991	11,792	51,463	1,251	49,759	5,625	19,179	666	--	139,736
1992	9,995	44,200	1,048	40,315	4,562	16,055	573	--	116,748
1993	9,568	36,027	1,137	35,839	3,984	15,593	405	90	102,643
1994	10,439	37,548	1,243	38,472	4,153	17,671	365	92	109,983
1995	12,717	36,088	1,579	48,502	5,284	23,726	438	101	128,434
1996	13,208	37,245	1,636	50,650	5,466	25,980	454	119	134,759
1997	14,194	40,216	1,700	54,604	5,481	30,150	450	132	146,927
1998	16,387	47,608	1,950	66,590	6,669	38,946	509	151	178,809
1999	19,367	60,343	2,315	81,875	8,070	52,681	593	178	225,422
2000	20,686	66,450	2,313	87,925	8,811	59,965	648	217	247,015
2001	21,311	66,547	2,430	89,040	9,167	63,279	607	184	252,564
2002	21,194	66,322	2,389	87,102	9,498	65,321	663	212	252,701
2003	26,851	33,869	8,333	65,287	6,788	83,965	1,631	169	226,893
2004	26,463	31,903	8,137	62,268	5,843	83,833	1,716	198	220,360
2005	28,484	34,082	8,749	65,600	6,209	90,156	1,740	188	235,208
2006	29,844	35,502	9,289	68,361	6,522	95,587	1,754	197	247,056
2007	29,827	35,334	9,364	68,074	6,498	96,144	1,680	172	247,093
Total	334,289	812,460	66,142	1,110,106	114,367	895,619	15,505	2,391	3,350,879
Mean	18,572	45,137	3,675	61,673	6,354	49,757	861	159	186,160

Table 4: Minor accidents according to accident type for the Spanish construction industry (developed by the authors based on MTAS primary data)

Table 5

SERIOUS	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08	TOTAL
1990	578	861	36	1,038	225	60	41	--	2,839
1991	581	839	40	1,024	228	77	41	--	2,829
1992	459	646	24	773	171	44	31	--	2,148
1993	485	528	27	764	175	44	22	55	2,098
1994	479	548	40	757	178	63	16	60	2,141
1995	563	458	48	910	217	69	18	58	2,341
1996	594	468	46	929	218	75	16	66	2,412
1997	577	452	45	927	197	63	16	57	2,333
1998	638	484	47	1,099	234	101	19	71	2,691
1999	740	556	42	1,257	274	110	22	79	3,079
2000	756	574	50	1,299	285	107	20	98	3,189
2001	787	605	55	1,330	285	118	20	98	3,297
2002	820	624	71	1,327	294	100	18	107	3,361
2003	1,155	416	217	1,167	253	221	69	88	3,586
2004	1,138	392	212	1,113	218	221	73	103	3,469
2005	1,077	376	192	1,047	191	199	61	95	3,238
2006	995	349	183	990	187	190	58	81	3,033
2007	976	354	184	927	191	190	57	76	2,955
Total	13,390	9,520	1,549	18,670	4,012	2,041	610	1,186	50,978
Mean	744	529	86	1,037	223	113	34	79	2,832

Table 5: Serious accidents according to accident type for the Spanish construction industry (developed by the authors based on MTAS primary data)

Table 6

VERY SERIOUS	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08	TOTAL
1990	36	30	3	100	14	6	5	--	194
1991	34	31	4	98	14	7	5	--	193
1992	29	22	2	67	10	1	4	--	135
1993	28	19	3	63	10	2	2	22	148
1994	29	17	4	52	9	1	3	18	132
1995	34	12	3	73	10	2	2	21	157
1996	39	14	5	72	11	3	2	20	166
1997	33	13	4	79	11	1	1	17	159
1998	38	12	4	89	12	1	1	19	177
1999	41	15	2	105	16	1	1	18	199
2000	37	21	3	108	13	5	2	29	218
2001	41	23	4	103	15	5	2	23	216
2002	36	13	8	86	14	5	1	19	183
2003	67	13	19	96	13	10	7	25	251
2004	66	12	19	92	12	10	8	29	247
2005	63	15	15	99	16	8	2	28	246
2006	65	14	11	103	15	3	2	29	242
2007	62	17	8	101	16	4	2	29	239
Total	771	310	113	1,578	220	66	44	341	3,443
Mean	43	17	6	88	12	4	2	23	191

Table 6: Very serious accidents according to accident type for the Spanish construction industry (developed by the authors based on MTAS primary data)

Table 7

DEATHS	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08	TOTAL
1990	75	13	20	178	29	7	3	--	325
1991	70	12	17	159	38	11	2	--	309
1992	61	4	7	123	21	0	3	35	254
1993	49	4	8	96	23	3	0	49	232
1994	54	9	18	96	22	3	0	39	241
1995	65	3	22	132	18	2	0	43	285
1996	79	1	22	88	21	1	0	43	255
1997	73	3	22	129	27	0	0	45	299
1998	71	6	11	149	22	2	0	42	303
1999	80	3	20	166	30	0	0	48	347
2000	65	2	15	166	31	0	0	65	344
2001	70	4	17	162	20	2	1	44	320
2002	77	2	13	166	24	0	0	62	344
2003	94	7	23	192	35	3	1	55	410
2004	84	6	20	171	31	3	1	49	365
2005	76	5	17	160	27	2	0	49	336
2006	66	4	16	140	23	1	1	42	293
2007	65	3	14	144	21	1	0	44	292
Total	1,274	91	301	2,617	461	40	10	752	5,546
Mean	71	5	17	145	26	2	1	47	308

Table 7: Fatal accidents according to accident type for the Spanish construction industry (developed by the authors based on MTAS primary data)

Table 8

Accident type	Maximum	Mean	Minimum
Ac01	42	37	35
Ac02	28	24	22
Ac03	27	22	20
Ac04	26	22	20
Ac05	33	28	26
Ac06	24	21	19
Ac07	30	24	20
Ac08	66	55	44

Table 8: Days of medical leave for each accident type for the Spanish construction industry (elaborated by the authors based on MTAS primary data)

Table 9

	CONCEPTS	Data				Cost (€)			
		M	S	VS	D	M	S	VS	D
1.	TIME LOST (TL)								
1.1	Time lost by the injured worker (HA = H * CH)					23.70	47.40	71.10	71.10
	Hours (H)	2	4	6	6				
	Cost per hour (CH)	11.85	11.5	11.85	11.85				
1.2	Time lost by co-workers (HO = NC* H * CH)					11.85	47.40	189.60	189.60
	Number of co-workers (NC)	2	4	8	8				
	Hours (H)	0.5	1	2	2				
	TOTAL TIME LOST					35.55	94.80	260.70	260.70
2.	TIME SPENT ON THE ACCIDENT BY OTHERS								
2.1	Senior management (HM = H * CH)					35.55	71.10	106.65	106.65
	Hours (H)	3	6	9	9				
2.2	Administrative personnel (HD = H * CH)					47.40	94.80	142.20	142.20
	Hours (H)	4	8	12	12				
2.3	Investigation of the accident (HI = H * CH)					474.00	948.00	1,422.00	1,422.00
	Hours (H)	40	80	120	120				
	TOTAL TIME SPENT BY OTHERS					556.95	1,113.90	1,670.85	1,670.85
3.	COST OF MATERIALS					0.00	500.00	1,000.00	2,000,00
	TOTAL COST OF MATERIALS					0.00	500.00	1,000.00	2,000.00
4.	TRANSFER AND SUBSTITUTION COSTS								
4.1	Temporary incapacity (DL * GS)					3,318.00	3,507.60	3,981.60	0.00
	Days of medical leave (DL)	35	37	42	0				
	Gross daily salary (GS)	94.80	94.80	94.80	94.80				
4.2	Transfer expenses (ambulance, taxi, etc.)					0.00	100.00	100.00	200.00
	TOTAL TRANSFER AND SUBSTITUTION COSTS					3,318.00	3,607.60	4,081.60	200.00
5.	LOSS OF PRODUCTION								
5.1	Stoppage of production activity					0.00	1,000.00	2,000.00	3,000.00
5.1	Overtime hours (OH = H * CH)					35.55	94.80	260.70	260.70
	Hours (H)	3	8	22	22				
5.2	Hiring a substitute (DL * GS)					3,318.00	3,507.60	3,981.60	663,60
	Days of medical leave (DL)	35	37	42	7				
	TOTAL COSTS OF LOSS OF PRODUCTION					3,353.55	4,602.40	6,242.30	3,924.30
	TOTAL COST OF THE ACCIDENT IN EUROS					7,264.05	9,918.70	13,255.45	7,555.85

Table 9: Accident cost calculation record applied to falls from heights for the Spanish construction industry (CT-Ac01) (developed by the authors)

Table 10

Code	Accident type	Minor	Serious	Very serious	Deaths
Ac01	Falls from heights	7,264.05 €	9,918.70 €	13,255.45 €	7,555.85 €
Ac02	Slips and trips	4,799.25 €	7,053.90 €	9,801.05 €	7,555.85 €
Ac03	Electrocution	4,420.05 €	7,062.85 €	10,411.45 €	7,555.85 €
Ac04	Collision with or getting hit by an object	4,520.05 €	7,062.85 €	11,221.85 €	7,555.85 €
Ac05	Entrapment	5,557.65 €	7,700.45 €	10,549.05 €	7,555.85 €
Ac06	Lifting (overstrain)	4,230.45 €	6,373.25 €	8,842.65 €	7,555.85 €
Ac07	Living things	4,420.05 €	6,942.05 €	9,980.25 €	7,555.85 €
Ac08	Heart attack	8,970.45 €	12,819.65 €	16,805.85 €	7,555.85 €

Table 10. Cost per type of accident (CT) for the Spanish construction industry (developed by the authors)

Table 11

	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08
MINOR	3.5060	10.6135	0.5134	13.1954	1.3925	8.2640	0.1447	0.0320
SERIOUS	0.1255	0.1311	0.0133	0.0928	0.0514	0.0204	0.0064	0.0165
VERY SERIOUS	0.0086	0.0042	0.0012	0.0191	0.0028	0.0008	0.0007	0.0047
DEATHS	0.0160	0.0012	0.0039	0.0321	0.0059	0.0006	0.0002	0.0105

Table 11. Case study: Number of accidents per type and severity (NW)

Table 12

	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08
MINOR	25,467.76	50,936.84	2,269.25	59,643.87	7,739.03	34,960.44	639.58	287.05
SERIOUS	1,244.80	924.77	93.94	655.43	395.80	130.01	44.43	211.52
VERY SERIOUS	114.00	41.16	12.49	214.34	29.54	7.07	6.99	78.99
DEATHS	120.89	9.07	29.47	242.54	44.58	4.53	1.51	79.34

Table 12. Case study: Expected cost of accidents per type and severity (CW)

Table 13

	Ac01	Ac02	Ac03	Ac04	Ac05	Ac06	Ac07	Ac08
MINOR	8,475.40	15,847.02	693.55	17,825.67	2,475.17	10,576.27	195.48	97.83
SERIOUS	321.23	214.39	19.86	138.56	98.67	29.01	10.47	63.35
VERY SERIOUS	25.07	8.06	2.22	33.95	6.37	1.31	1.44	21.72

Table 13. Case study: Recovery of accident costs per type and severity (RC)

Table 14

Abbreviation	Concept
α	Ratio of the budget due to labor
β	Ratio of the budget invested in prevention
BC	Budget of the construction project
BS	Base salary
CC	Total expected cost of occupational accidents in a construction project
CH	Worker's cost per hour
CN	Professional contingencies
CT	Cost of the accident per type
CW	Expected cost of the accidents at the work site
DL	Days of medical leave
ES	External suppliers
EX	Exposure time at the construction site
FI	Frequency index
GS	Daily gross salary
HA	Time lost by the injured worker
HD	Time spent on accident-related activities by administrative personnel
HH	Time spent in repairing damage at the construction site
HI	Time spent in investigating the accident
HM	Time spent on accident-related activities by senior management
HO	Time lost by other workers because of the accident
HS	Hours scheduled to complete a task of the construction project
IC	Insurance costs
LP	Loss of production or business
MTAS	Spanish Ministry of Employment and Social Affairs
NA	Number of accidents for the entire Spanish construction industry
NC	Number of co-workers affected by the accident
NH	Number of man-hours per million hours worked for the entire Spanish construction industry
NW	Expected number of accidents during the construction project
OH	Overtime hours
PC	Prevention costs
RC	Recovery of costs
SC	Transfer and substitution costs
SP	Profits not obtained by the company as a consequence of the accident
TE	Hospital transfer expenses of the injured worker
TL	Cost of the time lost
TR	Cost of the time spent by others on accident-related activities even if this time is not related to the production process

Table 14. Abbreviations