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The impact of health and safety investment on construction company costs

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ABSTRACT

This paper presents the most significant results of a study of the impact of health and safety investment on construction company costs. A questionnaire was designed and applied to a sample of a total of 40 construction works in progress in southern Spain. Analysis of the data produced reveals the interrelationships between variables relevant to the management of risk reduction, including the costs of safety measures of risk reduction, the occurrence of accidents and their cost, the material operating budget for the project and the health and safety plan budget. On the other hand, bivariate analysis of the initial hypotheses shows that the complex relation between the occurrence of accidents and their cost cannot be explained by any single variable. The predictive model that best fits the sample data is the Poisson truncated distribution. The results obtained with this distribution show that the average number of accidents varies directly with the total number of workers, the average number of subcontractors and the health and safety budget, while it varies inversely with the cost of accident prevention.

1. Introduction

In the construction sector, workplace accident rates are very high compared to other sectors (Mitropoulos et al., 2005; Abdelhamid and Everett, 2000; Montero et al., 2009; Loosemore and Andonakis, 2007; Hinze and Appelgate, 1991; Martínez Aires et al., 2010). The costs associated with these accidents are both human (not directly measurable) and financial, for companies and for society as a whole (sick leave, medical treatment, etc.) (Dorman, 1998). Other costs also arise, such as delays in project implementation, impaired company image or loss of market (Gosselin, 2004; Jallon et al., 2011).

The aim of this study is to examine and analyse the business costs related to the prevention of occupational hazards in the construction sector, with particular reference to the costs associated with construction work.

Regarding the situation in Spain in this respect, the National Survey on the Management of Health and Safety and Work (INSHT, 2009), reflecting the opinion of business leaders from different economics sector, reported that in 87.7% of workplaces where accidents had occurred in the previous 2 years, no data on their economic impact were available. When information was available on the costs arising from an accident, it was limited to the fees and subscriptions payable to the insurance plan for occupational accidents and diseases or to the National Social Security System (82.3% of the worksites surveyed where an accident had occurred in the past 2 years). Much less frequently, firms calculated the cost of activities aimed at preventing occupational risks (17.2%), the uninsured costs arising from lost production (15.6%) and the uninsured cost of downtime of other workers and managers (14.2%). Finally, the costs of impaired company image and loss of market were estimated by only 4% of the firms.

Several studies have analysed the economic aspect of health and safety at work and some have shown that employers do not consider investing in safety is financially profitable; in other words, the costs associated with workplace accidents are not considered to be so high that the company need invest in health and safety for the sole purpose of avoiding these costs (Brody et al., 1990; Andreoni, 1986; Gosselin, 2004; Jallon et al., 2011).

Moreover, models to analyse and calculate the costs of prevention in the construction industry are not easy to apply in this area. Firstly, because they are based on studies carried out in the manufacturing sector, and secondly, as pointed out by Andreoni (1986), because the traditional models for analysing these costs are limited to identifying and classifying them. According to Leopold and Leonard (1987) and Rikhardsson (2004), each company should tailor these models to its own circumstances. Hence, the calculation

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models need to be improved. This need is also reflected in our area of study, in which the compilation of financial data and accident rates is no simple matter at present.

Our goal, therefore, is to analyse the impact on a construction company of investing in health and safety measures in the implementation phase of a construction project, regarding the costs that the company might incur as a result of workplace accidents or deficiencies in health and safety measures. Other potential business benefits arising from such investment, such as the effects on the performance of workers of improved health and safety conditions and a better working environment are beyond the scope of this study; moreover, they have been examined by authors such as Hinze and Appelgate (1991) and Choi et al. (2011).

The methodology applied consists of two phases: the first is qualitative, concerning the design of the questionnaire and in the second is both quantitative and qualitative, and refers to the implementation of the survey at construction sites and the analysis of the results obtained. In the latter stage, the on-site work was of crucial importance, facilitating a systematic description of the social setting in which the construction work takes place.

On the basis of the literature review performed at the outset, and taking into account the field work data, we formulated seven initial sets of hypotheses concerning the different variables involved in health and safety costs and in accident rates on construction sites.

2. Materials and methods

A broad range of instruments can be applied to this type of study. Thus, the European Commission and the Europe Aid Cooperation Office have classified thirteen categories of instruments that can be used to evaluate projects, programmes and interventions (Martínez Aires et al., 2010).

Following our review of published research, taking into account the above recommendations, and the fact that this study has a technical aspect and a social one, in order to analyse firms' investment in the prevention of risks in the workplace, accidents and their costs, we developed a methodology that combines quantitative research techniques (the questionnaire) and qualitative ones (the panel of experts and participant observation).

The use of both quantitative and qualitative procedures is aimed at avoiding the bias inherent to each method. Although the methodology most often used in the evolution of scientific research has been the quantitative one (Pita Fernández and Pértegas Díaz, 2002), it is now increasingly necessary to adopt a qualitative approach in order to understand social phenomena in their natural environment, as in the case of construction works.

2.1. The sample

We selected a sample of 40 building works in Andalusia (Spain), at different stages of completion in 2008, and representing all levels of the target population. The characteristics of the population addressed by the questionnaire are as follows:

It consists of building work in progress in Andalusia (southern Spain) being the Site Manager and the Site Administrator the interviewees.

Site Manager is responsible for financial management and accident prevention on the site, and therefore in a position to provide most information about the work. Moreover, as an employee of the lead contractor company, able to provide comprehensive information about the company. Responsibilities sometimes include supervising the information provided by accident prevention experts.

On the other hand, due to the large number of questions related to the financial supervision of the works and cost control, Site Administrators were also addressed.

Therefore, the questionnaire was addressed to 80 individuals working at 40 construction sites.

2.2. The questionnaire

The use of a questionnaire provides comparability of responses and obtains quantitative measurements of a wide variety of aspects, both objective and subjective, regarding the target population, through the use of standardised procedures of inquiry (García Ferrando et al., 1986).

As shown by Amerigo (1993) and Azofra (1999), the questionnaire contains diverse types of questions: closed, open, dichotomous, categorised and single-answer, working from general issues toward more specific ones. The questions in this study, as reflected in Table 1, are grouped into blocks or subject areas, and their suitability was confirmed in a prior pilot test, whose aim was to develop a comprehensible, definitive questionnaire. This was done by interviewing various officials at some of the sites included in the sample.

The quantitative data obtained from the questionnaire (which consists of 116 questions), together with the hypothesis tests applied, enabled us to eliminate the effects of chance in the rejection or acceptance of each hypothesis, and to quantify its importance.

2.3. The panel of experts and participant observation

According to Hallowell and Gambatese (2010), in general, little is known about the costs of health and safety, accidents and their consequences. Furthermore, analysing this information may be complicated by differences in the procedure used to obtain it; as observed by Laufer (1987), data are often compiled at different moments of time, regarding different spaces and by different organisations.

The present study incorporates qualitative tools, the panel of experts and participant observation, to validate the questionnaire. We realise that one of the limitations attributed to qualitative methods is the difficulty in their generalisation (Pita Fernández and Pértegas Díaz, 2002). The panel's opinions are introduced, nevertheless, because although a subjective component, and therefore, a less predictive one, is introduced, this approach does allow the study to describe a dynamic reality, that of aspects concerning health and safety. The studies developed by Love et al. (2010), Hallowell and Gambatese (2010), Andriessen (1978) include the panel's opinion.

Participant observation, on the other hand, provides data on people, processes and cultures in qualitative research, and thus enables a systematic description in a particular social setting, which is the case of the building works examined in the present study.

2.3.1. Panel of experts

For this study, the purpose of the panel is to assess and validate the design and applicability of the initial questionnaire. The panel

Table 1
Types and numbers of questions included.

Subject	No. of questions
Type of construction work	4
Scheduled duration	4
Budget	6
Workers	8
Visits by works inspectors	11
Accidents	23
Costs	60

of experts is defined as a group of independent, distinguished specialists in at least one of the aspects analysed, who meet to issue a collective judgment, reached by consensus, on this aspect. If consensus is not possible, or is not necessary, the panel will reflect the different positions of the experts (EuropaAid Co-operation Office, 2005).

Accordingly, these experts gave their judgment on the initial questionnaire used in the pilot study, which was then modified to obtain the improved, definitive edition (questionnaire 0) that was applied to the study sample.

In selecting the experts, the following principles were taken into account: their professional experience, independence, capacity for teamwork and open mindedness.

The expert panel for this study consisted of eleven people, representing the business and economic aspects of the construction industry (1), the supervision and management of the prevention of occupational hazards in the workplace (3), personnel administration (2) and academics (5).

2.3.2. Participant observation

Given the limitations encountered in collecting data – fundamentally, the existence of different types of construction works in the sample – participant observation, by the principal researcher, was used for this study.

Participant observation is used to better understand the phenomena under study. It enables the compilation of different types of data, reduces people's possibility to interpret questions wrongly, contributes to the development of practical questions and enhances understanding and credibility. Thus, for our purposes, it is the optimal form of data collection. However, there are some disadvantages, such as the possibility that only aspects of superficial interest to the researcher are addressed, that informants may be selected incorrectly, leading to misinterpretation, that erroneous descriptions are made of behaviour, or that the data may be taken taking into account the researcher's own interests (politics, religion, etc.).

This approach enabled us to overcome the bias that might have occurred from the participation of different individuals in the collection of information *in situ*. Indeed, the collection of data by different researchers can lead to significant differences being recorded for the observations, depending on which researcher is responsible.

2.4. Field work

The field work was carried out in three phases. In *Phase 0*, a selection of the sample is done with all the construction works currently in progress, according to database records for Andalusia, following telephone confirmation that work was continuing. Once suitable sites had been selected for the sample group, we contacted the works manager for each one, explaining the purpose of this research and assuring full confidentiality. Subsequently, the work plan and the schedule for visits to the site were determined, in agreement with the managers in each case. We scheduled at least two visits to each site, except where the degree of progress was close to 100%, in which case a single visit was agreed.

In *Phase 1*, over a period of 6 months, two researchers visited each work site in the study sample. In the first visit, the study was presented; its purpose was explained and the schedule described: dates for visits, the timing of each phase and the documentation required. This first visit included a meeting attended by the works manager, the general managers, the accident prevention officer, the site administrator and the health and safety coordinator. Following this meeting, after determining the current phase of the construction work and the degree of implementation of the stipulated prevention measures, the questionnaire was completed and the supporting documentation provided. At 30–60 days after the first visit, a second one was made to obtain any outstanding documentation needed and to determine whether any new circumstance relevant to the questionnaire (accidents, inspection visits, etc.) had arisen.

Finally, *in Phase 2*, the information compiled is digitalized, using the IBM SPSS 15.0 for Windows database. Sometimes, during this phase, it was necessary to revisit the work site to correct errors in the completion of the questionnaire or to fill in missing information.

2.5. Statistical analysis

The variables defined for testing our hypotheses were quantitative in nature. The Kolmogorov test of normality showed that the variables did not follow a normal distribution, except for the variable *average number of lead contractor workers*. Consequently, non-parametric tests were used for the bivariate analysis performed, except for the tests involving the variable in question, in which case parametric tests were used.

To measure the correlation between two variables, we used Spearman and Pearson Rho coefficients, together with the corresponding tests of significance, at 0.05. Except for the hypotheses of the group 3, for which we have made a contingency table with contrast of chi-square association.

Taking into account that industrial accidents are discrete, uncommon and randomly-occurring events, the analysis was complemented by the use of the Poisson model, which is suitable for events that occur randomly and independently in time (Karlaftis and Golias, 2002). In these cases, a better fit was obtained with Poisson than with other logarithmic regression models (Mattar-Habib et al., 2008), so this model is reasonably applicable to the circumstances of this study.

The Poisson regression model is the one most commonly used for quantitative response variables with a skewed distribution, which is the case of the data in the study sample. Here, the Poisson model is the most appropriate and accurate predictive model. In the phenomena studied, i.e., accidents in the workplace, the response variable is discrete in all cases and therefore has a finite number of values. Furthermore, one of the characteristics of the Poisson model is the independence of the number of incidents within different intervals (Chua and Goh, 2005), which is the case of our study.

The measures used to determine the goodness of fit in the Poisson model are the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). AIC offers a relative measure of the information lost when a given model is used to describe reality and shows the tradeoff between bias and variance. In this way, it helps to select the model that minimises the negative likelihood penalised by the number of parameters. From a Bayesian perspective, BIC is designed to find the most probable model given the data. Both, AIC and BIC, do have the same aim of identifying good models, even if they differ in their exact definition of a good model (Aquad, 2010).

3. Theory

The variables studied are related to the system applied to prevent accidents in the workplace in the construction industry, and to the costs arising from the implementation of such preventive measures and from the occurrence of accidents.

We define the costs associated with health and safety for construction companies as the consumption value of productive factors, goods and services, utilised in implementing actions by the company to improve working conditions and to reduce accident rates in construction sites, and the negative value derived from the occurrence of incidents and/or accidents. Understanding of these issues is of significance for risk reduction management in such companies (Ibarrondo-Dávila et al., 2012).

Costs related to health and safety in the workplace henceforth, termed safety costs, can be classified into two groups as follows:

1. *Safety costs:* incurred to ensure health and safety at the workplace. We distinguish between *prevention* costs and those of *evaluation and monitoring*.

Prevention costs are those incurred in order to comply with legal requirements with respect to accident prevention, to implement measures to prevent accidents during construction work and to improve health and safety conditions in all areas of the work performed. In relation to *Evaluation and monitoring costs*, these are derived from the actions taken by the company for appropriate testing and maintenance of the health and safety measures adopted, regarding every facet of the work in question, with the aim of reducing or minimising the risk of accident or occupational disease.

2. *Cost of non-safety:* are those produced by not ensuring health and safety at work, i.e., the costs a company must meet following accidents, as well as those that may arise from breaches of safety regulations. In turn, we distinguish between tangible and intangible costs of accidents.

Tangible costs of accidents reflect the costs associated with the occurrence of an accident at work, which can be estimated or calculated using traditional cost accounting methods, while *Intangible costs of accidents,* according to Gosselin (2004), are the costs which are not measurable in economic terms or for which there are no performance indices to measure their impact on the organisation, such as impaired company image, low worker morale, labour disputes or loss of market.

3. *Other extraordinary costs:* all losses provoked by events that cannot be prevented by the technical or human resources available to construction works, or which are totally unavoidable, such as natural disasters. This cost category includes all the items that are beyond the scope and control of management, and thus are classed as *uncontrollable costs*, which cannot be incorporated into a structured model designed to control costs regarding safety in the workplace.

Both intangible and extraordinary costs are excluded from this study, the first because, in general, they are neither calculated nor estimated in a construction project, and the second because, being uncontrollable as far as works managers are concerned, they cannot be included in a structured calculation model.

The following variables related to safety management in a construction site have been considered; contract operating budget, health and safety budget, type of labour contract, stage of progress of the project, project award discount and penalties.

The contract operating budget (COB) is considered the material operating budget (MOB), which is the sum of the budget items for a construction project, plus overheads (cost of administration and general management of the construction company) and profit.

The health and safety budget (HSB) shows the financial value of the preventive measures set out in the contractor's Health and Safety Plan, based on the Health and Safety Study conducted previously. These documents are obligatory following the transposition into Spanish law of Directive 89/391/EEC, applicable to all member states of the European Union (Official Journal of the European Communities, 2002).

The type of contract and its influence on accident rates has been highlighted by several authors (Guadalupe, 2003). More attention is paid to permanent workers, regarding accident prevention measures, than to temporary ones (Camino López et al., 2008). Subcontracting and firm size are other variables that have been mentioned as possibly related to accident levels (Hinze and Gambatese, 2003). In this paper, we distinguish between direct employees, hired by the lead contractor for the project, subcontracting firms and workers employed by these subcontractors.

The stage of progress of the project is considered the percentage of work completed with respect to the total construction project, in economic terms.

Other variable, project award discount, shows the difference between the COB of the final approved project and the amount of the tender selected or awarded.

Finally, penalties has been considered as those stipulated by the Business Offences and Penalties Act (MTAS, 2000) applicable for infractions regarding the prevention of occupational hazards. If safety rules are broken, the corresponding penalties represent a cost to the company that is taken into account in this study.

The relationships between the above-mentioned variables concerning safety budgets and costs, and their relation with accidents occurring at the construction sites examined are analysed.

The initial hypotheses are summarised as the following ten groups.

Group 1: Hypotheses relating the size of the project with safety costs. The first hypothesis is that *higher-budget projects involve greater spending on health and safety measures*. This is then broken down into four sub-hypotheses.

- Hypothesis 1.1: The greater the MOB, the greater the budget for the HSP.
- Hypothesis 1.2: The greater the budget for the HSP, the higher the real costs of accident prevention.
- Hypothesis 1.3: The greater the MOB, the greater the relative weight of the budget for the HSP in the MOB.
- Hypothesis 1.4: The greater the MOB, the higher the relative cost of accident prevention within the MOB.

Group 2: Hypotheses relating diverse cost variables with accident rates:

- Hypothesis 2.1: The higher the cost of prevention, the lower the cost of accidents.
- Hypothesis 2.2: The higher the health and safety budget, the lower the number of accidents.
- Hypothesis 2.3: The higher the health and safety budget, the lower the cost of accidents.

Group 3: Hypotheses relating the cost of prevention and the cost of accidents for each phase of project implementation. As the works projects in our sample were at various stages of implementation and as the risks and protection measures vary in each such phase, we tested the following hypothesis:

- Hypothesis 3.1: In the structures, installations, cladding and urbanisation, the higher the accidents prevention cost, the lower the cost of accidents.
- Hypothesis 3.2: In the remaining phases, the higher the accidents prevention cost, the lower the cost of accidents.

Group 4: Hypotheses relating the costs of accident prevention with the degree of progress of the project, in order to determine whether, as it advances, the preventive measures taken become less costly.

- Hypothesis 4.1: As the project advances, the cost of protective measures decreases.

Group 5: Hypotheses relating the number of accidents on site with the number of workers (employed by the lead contractor, by subcontractors, and in total) and with the number of subcontractors.

- Hypothesis 5.1: The higher the number of workers in total, the higher the number of accidents on site.
- Hypothesis 5.2: The higher the number of workers employed by the lead contractor, the higher the number of accidents on site.
- Hypothesis 5.3: The higher the number of workers employed by subcontractors, the higher the number of accidents on site.
- Hypothesis 5.4: The higher the number of subcontractors, the higher the number of accidents on site.

Group 6: Hypotheses relating the costs of occupational accidents with the number of workers (employed by the lead contractor, by subcontractors, and in total) and with the number of subcontractors. As in the Group 5 hypotheses, we analysed the relationship between the different types of labour contract and the costs of accidents.

- Hypothesis 6.1: The higher the number of workers in total, the higher the cost of accidents on site.
- Hypothesis 6.2: The higher the number of workers employed by the lead contractor, the higher the cost of accidents on site.
- Hypothesis 6.3: The higher the number of workers employed by subcontractors, the higher the cost of accidents on site.
- Hypothesis 6.4: The higher the number of subcontractors, the higher the cost of accidents on site.

Group 7: Hypothesis relating the costs of accidents with the degree of progress of the project.

- Hypothesis 7. 1: The higher the degree of progress of the project, the higher the cost of accidents on site.

4. Results and discussion

This section presents the results of the statistical analysis of the data obtained from the survey of the construction projects in our sample. First, a descriptive analysis of the sample is performed, followed by a discussion of the statistical test applied to the initial hypotheses, using bivariate analysis, and finally we consider the Poisson model.

4.1. Descriptive analysis of the survey sample

In the sample selected, 45% of the projects are privately developed and 55% are public-sector promotions. Moreover, 40% of the projects are civil engineering works and 60% are building works; and 47.5% of the projects have a contract execution term between 18 and 24 months, 55% of the projects near to completion, and over 80% of the work finalised.

The monthly statistical monitoring of the site workers provided the details shown in Table 2. A notable finding is that the average number of workers employed by the lead contractor in the civil engineering works (5.27) is higher than in the building works (3.52). In contrast, the average number of workers hired by subcontractors is higher in building works (8.21) than in civil engineering (2.89). An average of 4.25 subcontractors is involved in each building project, compared with 1.84 in the civil engineering works.

Table 2
Average distribution of workers.

Type of project	No. projects	Monthly average lead contractor workers	Monthly average subcontractor workers	Monthly average subcontractors
Building	24	3.52	8.21	4.25
Civil		engineering	16	5.27
2.89	1.84			
Total	40	4.22	7.97	4.39

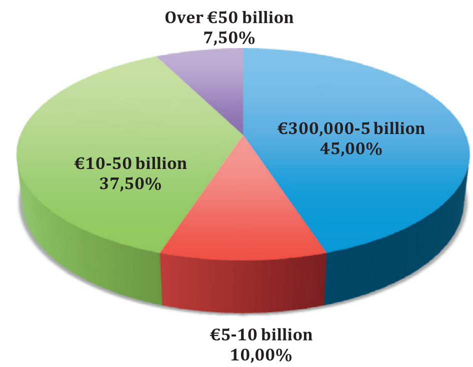

Fig. 1. Distribution of the number of projects by COB.

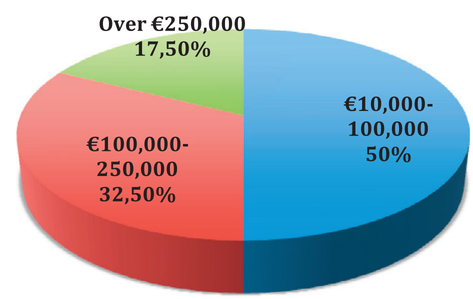

Fig. 2. Distribution of the number of projects by HSP.

The contract operating budget (COB) is indicative of the size of the project. As reflected in Fig. 1, in 45% of the projects, the COB was between 300,000 and five million euros (classified as small projects), and in 37.5% the COB was 10–50 million euros (large projects).

Another economic variable analysed was the budget for the Health and Safety Plan (HSP). In this respect, 50% of the projects had a budget of 10,000–100,000 euros, as shown in Fig. 2.

The sample data reflected a total of 178 reflected, which occurred between February 2002, as reflected in the data from the accident investigation in the corresponding construction site, and May 2008 occurrence date corresponding to the last accident investigated. The mean incidence by 43.17%, has been measured by the number of accidents per thousand persons exposed (Bestraten and Turmo, 1982). Fig. 3 shows that 55% of the accidents occurred during the structures phase and 14% in the earthmoving phase, these two phases being associated with most accidents in the sample. The phases of installations and finishing each accounted for 6.18% of accidents. In the remaining phases, the accident rate was below 5%.

The sample produced 86 accidents that affected the lead contractor's staff and 92 in which subcontractors' staff were injured, corresponding to 48.31% and 51.68% of total accidents,

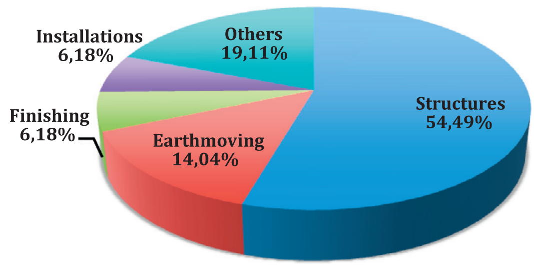

Fig. 3. Distribution of accident rates by project phases with respect to total number of accidents.

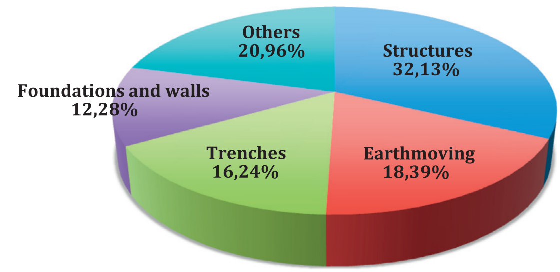

Fig. 4. Distribution of accident prevention costs per phase with respect to total cost.

Table 3
Distribution of accidents among lead contractors and subcontractors by construction phase.

Phase of project implementation	No. of lead contractor's workers affected		No. of subcontractors' workers affected		Total number of workers affected in each phase
	No. of workers affected	% of total	No. of workers affected	% of total	
Structure	35	36.08	62	63.90	97
Earthmoving	22	88.00	3	12.00	25
Finishing	5	45.45	6	54.54	11
Installations	2	18.18	9	81.81	11
Cladding	6	66.66	3	33.33	9
Urbanisation	4	57.14	3	42.85	7
Drains	3	50.00	3	50.00	6
Foundations	0	0.00	3	100.00	3
Aggregates	2	100.00	0	0.00	2
Crane operation	2	100.00	0	0.00	2
Laying out and marking	2	100.00	0	0.00	2
Trenches	2	100.00	0	0.00	2
Other	1	100.00	0	0.00	1
Total	86		92		178

respectively. This distribution was found to vary when we analysed the accidents suffered by workers employed by the lead contractor and by subcontractors at different stages of the construction project. Thus, in terms of the phases associated with most accidents, as shown in Table 3, in the structures phase, the accidents affecting the lead contractor's workers represent 36.08% of the total number of accidents, in contrast to the 63.90% of subcontractors' workers affected. However, in the earthmoving phase, 88% of those injured were lead contractor's workers, compared with the 12% who were employed by subcontractors.

Analysis of accidents according to the degree of progress of the project shows that 57.30% of accidents occur in the first third of the project. Moreover, the total cost of health and safety measures in our sample was €4.27 million. As shown in Fig. 4, 32.13% of this total cost corresponded to the structures phase and 18.39% to the earthmoving phase. Consequently, the two phases in which the companies surveyed spent most on accident prevention were also those in which the accident risk is greatest. Finally, the total cost of the 178 accidents that took place in our sample was €3.8 million.

4.2. Bivariate analysis

The initial hypotheses were tested by bivariate analysis, using Spearman and Pearson Rho coefficients and their corresponding tests of significance at a level of 0.05. Table 4 summarises the results of the hypothesis tests, showing whether or not they were confirmed.

Table 4, thus, shows the following: the four Group 1 hypotheses, regarding the material operating budget, the health and safety budget and the accident prevention cost are confirmed, in terms of both absolute and relative value.

With respect to the hypotheses forming Group 2, there is a significant relationship between the variables analysed, but in the inverse sense to the initial assumptions, which, therefore, are rejected. Consequently, we conclude that a higher HSB is not associated with any decrease in the number of accidents or their cost. While it seems a contradiction, the absence of significant relationship between the safety budget and the number of accidents might be justified by the influence of other factors. Indeed, a higher HSB might be motivated by a higher complexity or size of building sites, and even greater risk, factors influencing the number of accidents. Probably, all the results analysed are affected by the comparison of worksites with different levels of risk and complexity.

With respect to the hypotheses forming Group 3, there are significant differences in the accident rates and the costs of accident prevention between the different stages of project implementation, because in a construction project the risks and preventive measures associated with each phase are different.

Our analysis of this group by project stage shows that in the phases of structure, installations, cladding and urbanisation, as the cost of accident prevention increases, the cost of accidents decreases, and so hypothesis 3.1 is confirmed. As shown in Fig. 5, these phases represent 69.66% of total accidents and account for 44.86% of total prevention costs. However, in the other phases, hypothesis B is rejected, i.e., increased costs of prevention are associated with higher costs of accidents.

As shown in the descriptive analysis, most accidents in the sample occurred in the first third of the completion of the project. Therefore, we would expect a higher cost of prevention during this period. However, in contrast to the Group 4 hypotheses, the bivariate analysis did not reveal any significant association, i.e., the cost of prevention is independent of the degree of progress of the work.

With respect to the hypotheses for Group 5, significant results were obtained in three of the four cases. Thus, the accident rate is directly related to the number of total workers, the average number of subcontractors' employees and the average number of subcontractors. The latter relationship has been reported elsewhere, such as the study by Toole (2002). However, we did not find the accident rate to be related to the average number of lead contractor's workers.

With respect to Group 6, three of the four hypotheses were verified, in the same sense as those of Group 5. Thus, the cost of accidents is related to the total number of workers, the average number of subcontractors' employees and the average number of subcontractors, and so the larger the value of these variables, the greater the cost of the accidents that take place. In fact the subcontracting has been noted by several authors as one of the causes of accidents in Spain (Guadalupe, 2003).

Finally the hypothesis for Group 7 was not confirmed, and so we conclude that the degree of progress of the project has no significant relationship with the cost of accidents.

Table 4
Summary of hypothesis tests.

Code	Hypothesis	Rho spearman	Pearson	Confirmed?
1.1	The greater the MOB, the higher the budget of the HSP	0.897	0.868	Yes
1.2	The higher the budget of the HSP, the higher the APC	0.544	0.805	Yes
1.3	The greater the MOB, the greater the relative weight of the budget for the HSP in the MOB	0.897	0.868	Yes
1.4	The greater the MOB, the higher the relative cost of accident prevention within the MOB	0.897	0.868	Yes
2.1	The higher the APC, the lower the cost per accident	0.753	0.674	No
2.2	The higher the health and safety budget, the lower the number of accidents	0.582	0.634	No
2.3	The higher the health and safety budget, the lower the cost of accidents	0.446	0.607	No
3.1	In the structures, installations, cladding and urbanisation, the higher the APC, the lower the cost of accidents	Chi-cudrado de Pearson: 0.362	Yes	
3.2	In the remaining phases, the higher the APC, the lower the cost of accidents	Chi-cudrado de Pearson: 0.367	No	
4.1	As the project advances, the cost of protective measures decreases	0.066	−0.081	No
5.1	The higher the total number of workers, the higher the number of accidents	0.437	0.321	Yes
5.2	The higher the number of lead contractor workers, the higher the number of accidents	0.068	0.000	No
5.3	The higher the number of subcontractor workers, the higher the number of accidents	0.488	0.321	Yes
5.4	The higher the number of subcontractors, the higher the number of accidents	0.534	0.529	Yes
6.1	The higher the total number of workers, the higher the cost of accidents	0.626	0.045	Yes
6.2	The higher the number of lead contractor workers, the higher the cost of accidents	0.065	0.164	No
6.3	The higher the number of subcontractor workers, the higher the cost of accidents	0.360	−0.002	Yes
6.4	The higher the number of subcontractors, the higher the cost of accidents	0.454	0.437	Yes
7.1	The more advanced the stage of the project, the higher the cost of accidents	0.755	−0.103	No

HSP, Health and Safety Plan; APC, Accident prevention cost; MOB, Material operating budget.

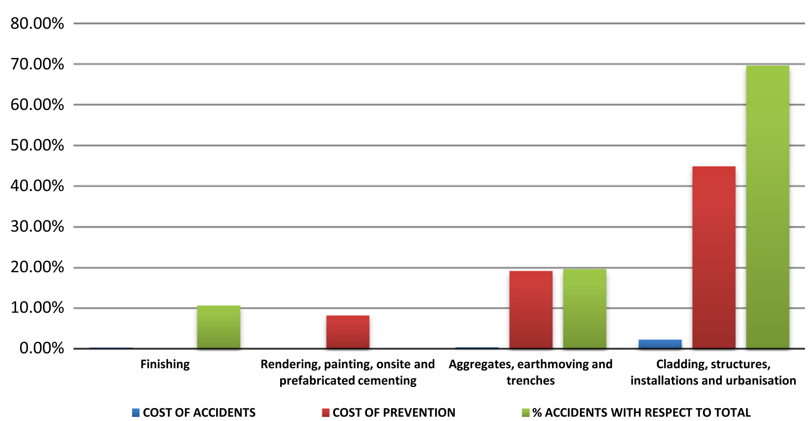

Fig. 5. Costs of prevention and of accidents in each stage of the project, and percentage of accidents with respect to total accidents.

4.3. Poisson model

As shown in our bivariate analysis, a significant relationship between the variables was only found in ten of the twenty-one hypotheses analysed, and so in general the statistical tests applied do not confirm our initial hypotheses. In our view, the occurrence and the costs of accidents are complex issues that do not depend on a single variable. These conclusions are consistent with those proposed obtained by other researchers such as Abdelhamid and Everett (2000), Gibb et al. (2001,2006) and Haslam et al. (2005).

Consequently, we applied another predictive statistical model, the Poisson model, which is more appropriate to the problem studied. Table 5 shows the results obtained by applying least squares regression, the Poisson regression, the truncated Poisson Regression and negative binomial regression to the variables found to be significant.

After this, as shown in Table 5, the predictive model that best fits our sample data is the truncated Poisson distribution, which gives the lowest absolute value for AIC and BIC. According to the results obtained with this distribution, the average number of accidents varies positively with the total number of workers, the average number of subcontractors and with the health and safety budget, and varies inversely with the cost of accident prevention. It means that being equal all the variables, in our predictive model, the number of employees, the number of subcontractors and the health and safety budget must be controlled in order to control the number of predictable accidents in the construction sites. The relationship between the average number of accidents and the degree of progress of the project is quadratic, as discussed below. The following model is obtained.

$$\text{Average number of accidents} = \exp\{0.008W + 0.050\overline{SC} - 0.000\text{PC} + 0.000\text{HSB} + 0.038P - 0.0001P^2\}$$

where W is the total number of workers, $\overline{SC}$ the average number of subcontractors, PC the accident prevention cost, HSB the health and safety budget, and P is the degree of progress.

From this, we conclude that, when the other regressors remain unchanged:

- The number of accidents is positively associated with the total number of workers, and the relation is significant.
- The number of accidents is positively associated with the average number of subcontractors, and the relation is significant.
- The number of accidents is inversely associated with the cost of accident prevention, and the relation is significant.

Table 5
Results of regression analysis (*p*-values in brackets).

Statistical variables	Least squares regression	Poisson regression	Truncated Poisson regression	Negative binomial regression
Total number of workers	**0.031(0.005)**	**0.006(0.003)**	**0.008(0.005)**	**0.006(0.007)**
No. of subcontractors	**0.235(0.067)**	**0.044(0.038)**	**0.050(0.047)**	**0.054(0.057)**
Prevention cost	−**0.000(0.095)**	−**0.000(0.036)**	−**0.000(0.029)**	−**0.000(0.052)**
Health and safety budget	0.000(0.154)	0.000(0.755)	0.000(0.919)	0.000(0.527)
Degree of progress	0.098(0.211)	0.030(0.126)	0.038(0.105)	0.023(0.179)
Degree of progress^2	−0.001(0.140)	−**0.0004(0.044)**	−**0.0001(0.030)**	−**0.0003(0.058)**
N	40	40	40	40
AIC	211.438	185.826	**172.655**	182.568
BIC	225.147	199.533	**186.364**	197.990

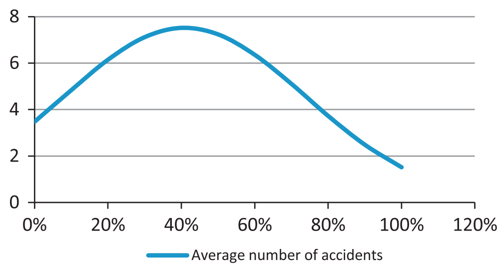

Fig. 6. Average number of accidents for degree of progress.

The degree of progress of the work has a quadratic effect on the average number of accidents. Using the above model, it is possible to predict the change in the average number of accidents according to the degree of progress, while other regressors remain constant. We constructed a graph to demonstrate this, and as shown in Fig. 6 we constructed a graph to demonstrate this, and it can be seen that the average number of accidents is maximum, at about 7, for a degree of progress close to 47%.

At an early stage of project completion, the relationship between the average number of accidents and the degree of progress is positive. However, above 47% completion, this relationship is negative. The quadratic effect of the average number of accidents, with respect to the degree of progress, confirms some of our findings set out in the descriptive analysis of the sample. Thus, in the construction projects that make up our sample, most accidents occur in the initial phases, such as earthmoving and structures. Moreover, most of the accidents (57.3%) are concentrated in the first few months of work, corresponding to 0–30% progress.

5. Conclusions

This paper presents the main results of the analysis of data obtained from a survey of 40 construction sites in Andalusia (southern Spain), with the aim of determining the interrelationships between the variables most relevant to the management of risk reduction in the workplace, namely the costs of accident prevention, the occurrence of accidents and their cost, the material operation budget and the health and safety plan budget, among others.

The bivariate analysis applied to verify the initial hypotheses led us to draw the following conclusions:

The greater the material operation budget and the health and safety plan budget, in construction projects, the greater the cost incurred in preventive measures, in both absolute and relative terms, i.e., the larger the size of the project, in economic terms, the greater the investment made in health and safety measures.

We observed significant differences in accident rates and in accident prevention costs among the diverse stages of implementation, because the risks and preventive measures associated with each phase are different in the construction industry. In particular, the phases of structures, installations, cladding and urbanisation confirmed our initial hypothesis according to which as prevention costs increase, the cost of accidents decreases. In contrast, in the other phases, this hypothesis cannot be accepted; higher costs of accident prevention are associated with higher costs of accidents.

Accident rates are directly associated with the number of total workers in the project, the average number of subcontractors' employees and the average number of subcontractors. However, we did not find the level of accidents to be related to the average number of lead contractor workers.

Furthermore, the cost of accidents is directly related to the total number of workers, the average number of subcontractors' workers and the average number of subcontractors. Thus, the higher the values of these variables, the greater the cost of accidents.

The cost of accident prevention is independent of the stage of progress of the project.

However, bivariate statistical analysis only revealed a significant relationship between the variables analysed in ten of the twenty-one hypotheses. This corroborates the view that the occurrence of accidents and their cost are complex problems that do not depend on a single variable. In consequence, other predictive statistical models have been considered in search of one more appropriate to the problem in question.

The model that best fits the sample data is the truncated Poisson distribution, which gives the lowest absolute values for AIC and BIC. According to the results obtained with this distribution, the average number of accidents varies positively with the total number of workers, the average number of subcontractors and the health and safety budget, while it varies inversely with the cost of accident prevention. The average number of accidents and the degree of progress of the project present a quadratic relation.

Application of the Poisson model enables us to predict the number of accidents that will occur on a construction site, from a set of significant variables. Once the number of accidents on a construction site has been estimated, it is possible to estimate their cost, and hence the total cost of safety on the work site, to be added to the cost of prevention.

After the statistical treatment done, it is shown the necessity to collect and analyse data related with health and safety costs. Afterwards, it is classificated these costs, in order to optimise decision-making in the business in terms of occupational health and safety. Thus, managers have a means of obtaining useful information for decision making with respect to accident prevention in the construction industry.

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