USING EMPIRICAL DATA TO IDENTIFY EFFECTIVE SAFETY MANAGEMENT STRATEGIES IN CONSTRUCTION COMPANIES

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ABSTRACT

This paper explores the use of mathematical analyses methods to identify the components of effective management strategies applied by a safety management organization in construction companies. The authors believe that effective methods and strategies are closely related to Lean Construction strategies and one objective of this research was to explore this hypothesis.

In Chile, "Safety Mutuals" are nonprofit organizations that provide medical insurance and technical assistance on safety management to companies in all the economic areas. In the last 40 years these institutions have helped to reduce accidents to 1/5th in the Chilean companies. Over the years they have introduced hundreds of methods/practices to prevent and mitigate accidents; however, there is little evidence of the effectiveness of individual or combined methods used in companies to manage safety issues.

The authors selected a sample of over 1100 construction firms, and 221 individual methods/practices applied in these companies to analyze their effectiveness in reducing injury rates over a period of 4 years. Different methods were used to analyze a massive database including: visual analysis of graphical information, statistical analyses, and several data mining techniques. A survey to companies was also prepared to complement the data analysis and identify the relationship of safety methods with lean practices but these results are not available yet and will be reported in a future paper.

The analysis of safety performance and associated safety practices allowed the identification of trends, individual and combined impacts of practices and the selection of analysis methods that have the potential to support the design of safety management strategies in the near future.

KEY WORDS

Construction, Safety Management, Partnering, Relational Contracting.

INTRODUCTION

Workplace Safety and Health has always been a sensitive issue at both the company and country level, and not just the costs of having an accident in a company, but also

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by the fact that they are human lives that are affected by these accidents. Heinrich (1931) makes the concept of prevention identifiable in the domino theory, which posits that accidents are caused by unsafe behavior or physical danger, and that should remove this "domino" to avoid the accident. Bird and Germain (1985) incorporated the concept of multiplicity of sources. Thus, during the past 30 years, researchers have been trying to identify the main factors affecting safety performance on construction projects. Hinze and Wilson (2000) and the Construction Industry Institute (CII1993) identified five practices with the greatest impact in reducing accidents: project task and safety planning; orientation and safety training; incentives program; written safety program of alcohol and substance abuse; Investigation of accidents and incidents. Subsequently, these five techniques were extended to nine (Hinze, 2002). Other researchers have helped to identify other practices' impact in reducing accidents; some contributors are Mohamed (2002), Fang et. al (2004), Fung et. al (2005) and Abudayyech et. al (2006). Recently, Rázuri et al (2007) identified and assessed the impact of 16 practices for risk prevention. In this study, it was postulated that there is an incremental contribution of safety performance according to the combination of these practices.

In order to explore Razuri et al proposal further, the authors contacted organizations that manage massive data on safety management. In Chile, "Safety Mutuals" are nonprofit organizations that provide medical insurance and technical assistance on safety management to companies in all the economic areas. In the last 40 years these institutions have helped to reduce accidents to 1/5th in the Chilean companies. They use hundreds of methods/practices to prevent and mitigate accidents; however, there is little evidence of the effectiveness of individual or combined methods used in companies to manage safety issues. The authors, working with the Safety Mutual of the Chilean Chamber of Construction (SM) selected a data sample of over 1100 construction firms, and 221 individual methods/practices applied in these companies to analyze their effectiveness in reducing injury rates over a period of 4 years. Different methods were used to analyze a massive database including: visual analysis of graphical information, statistical analyses, and several data mining techniques. A survey to companies was also prepared to complement the data analysis and identify the relationship of safety methods with lean practices but these results are not available yet and will be reported in a future paper.

The analysis of safety performance and associated safety practices allowed the identification of trends, individual and combined impacts of practices, and the selection of analysis methods that have the potential to support the design of safety management strategies in the near future.

DEVELOPMENT OF THE RESEARCH

METHODOLOGY

The methodology included a literature review, interviews with safety specialists from companies and SM, the analysis of data from the Safety and Occupational Health Data System of the SM, and the application of a survey to companies to complement information from the SM database. The SM database includes data for over 1,100 construction companies, and prevention practices carried out every year. It was also

possible to raise additional information such as company size, building indicators and other data to characterize the companies.

It was very difficult to obtain and process data for analysis from the original SM database. The system is designed to store information, but not for analysis. Significant efforts were made to improve the quality of information, because the original data is introduced by the Safety Experts from each of the companies who may have different criteria for defining prevention activities. To build the database to be used in the analysis, the following activities were carried out:

- Filter companies by category, in order to analyze only the construction companies in the SM. This gave a total of 1,180 companies.
- Identify for each acceding country (companies), prevention practices undertaken each year. We identified a total of 221 different prevention activities.
- Group prevention activities into more complete practices to simplify the analysis. Prevention practices conducted by the SM covered only seven practices of the total, Staff and Equipment Safety Commitment Management, Specialized Training for Workers Training Program for the Administration, the SM Activities, Incentives and Information Safety Accidents and Incidents.
- Sort companies by size of business.
- Calculate the rate of accidents per year for each company.
- 4 years of records. Data from 2005 to 2008.
- 4,506 total annual records.

ANALYSIS OF RESULTS

Analysis of Combinations of Practices

From the analysis, it was found that seven practices had a statistically significant impact on the accident rate in companies that have had accidents. Antillon et al (2011) discuss the interaction of some individual practices with Lean Production principles in a discussion that can be very valuable in designing a safety management strategy. The seven practices are the following:

Accident and Incident Documentation: activities related to the capture of information of accidents and incidents.

Staff and Security Equipment: All activities carried out by Security Staff and activities related with the Safety Equipment that workers should use.

Management Commitment: activities that demonstrate the willingness and commitment to safety from management, which otherwise would not be carried out.

Specialized Training for Workers: all activities such as courses, workshops, seminars, and all kind of safety training for workers

Training Program for Management: the same that for workers, but focused on the management of the company.

Mutual: all activities or programs unique to the SM under study.

Safety Incentives: all kind of recognition for good safety records, such as awards, dinners, or even monetary awards

All possible combinations of these practices were identified for further analysis; they will be called "strategies" in the following discussion. Figure 1 shows 80 identifiable different strategies (combinations) found, ordered in the tornado graph form suggested by Rázuri et al (2007) according to the difference between the accident rate for each strategy compared to the average accident rate. It can be seen that the decrease in accident rate between strategies has a good fit to the linear form proposed. Also, 20% of the strategies recorded accident rates higher than average, but they account for two thirds of all records.

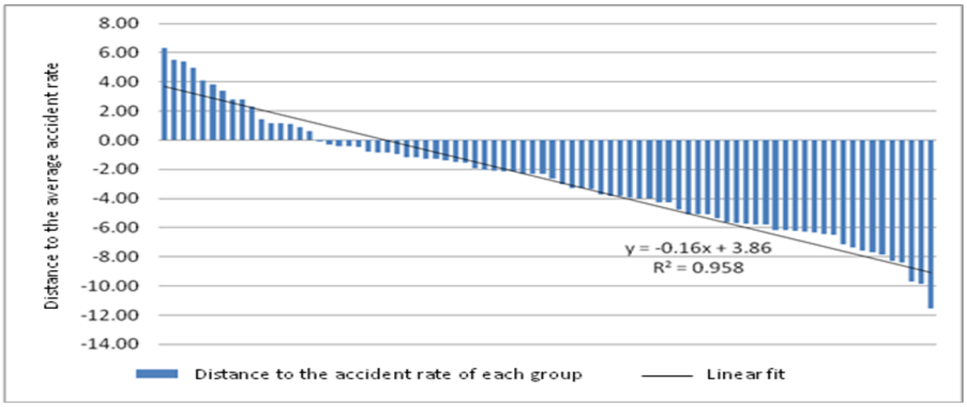


Figure 1 - Tornado graph of accident rate variation for each strategy

Figure 2 shows that as the number of prevention practices increases, accident rate decreases. However, this variable presents high variability, showing that more important than the number of practices is the right combination of them.

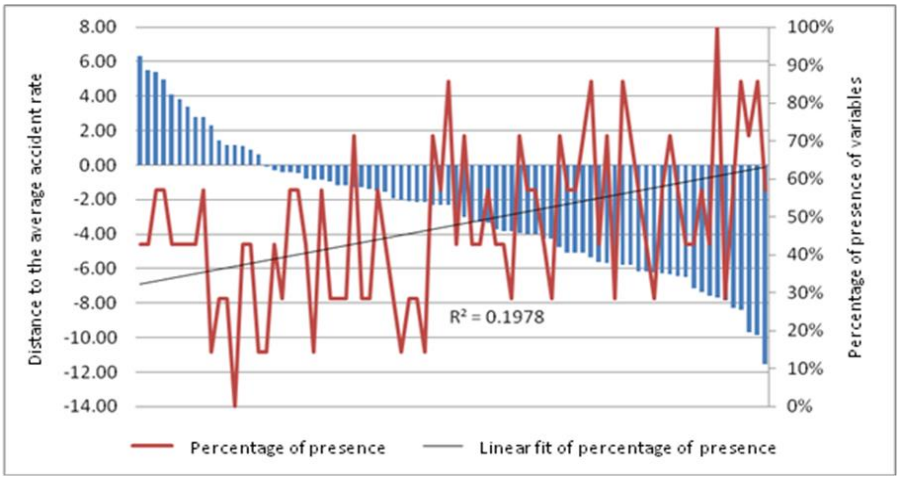


Figure 2 - Relative accident rate and presence of practices

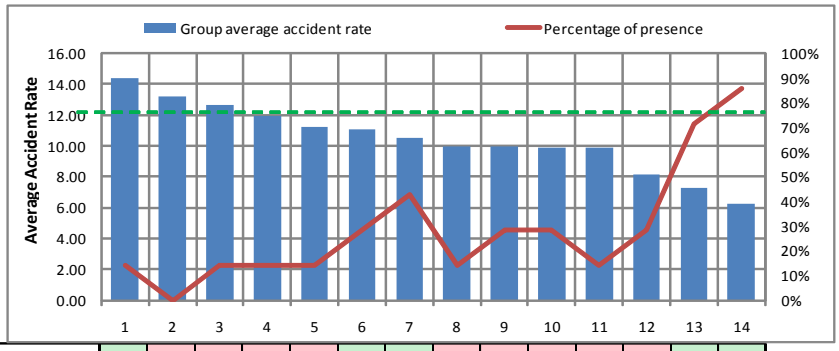
For purposes of further analysis, we considered only those combinations of practices where at least 30 records were available, giving a total of 14 strategies. These strategies are shown in Figure 3, which includes the average accident rate of

each strategy, the percentage of presence of prevention practices, and the average accident rate for companies that had accidents in the period analysed.

Some preliminary observations:

- Safety Incentives were not present in the strategies analysed.
- These 14 strategies represent 84.2% of the records in the present study.
- The top nine strategies have an average size of 1.2% of total records.
- The second worst strategy is widely adopted and accounts for 55% of total records.
- The most common strategy had twice the accidents of the best strategy.

Figure 3 allows for a global review of the risk prevention strategies. In general, the most effective strategies (lower accident rates) have more practices implemented. The most popular strategy and second-worst performance did not have any of the 7 practices analyzed. This confirms previous results that indicated the higher the number of prevention activities the lower the accident rates. However, this trend presents interesting features, for example, strategies 6, 9 and 12 have two practices each, one of them is "Staff and Safety Team", and vary only in the presence of the practices "Accident and Incident Documentation", "Management Commitment" and "Training program for administration", respectively. Only with this difference, the strategy No. 6 has an average accident rate of 11.08; the No. 9 has a 9.94 accident rate and No. 12 an 8.18 average rate. With an equal number of prevention practices, there are differences of up to 26% in the accident rate, highlighting the importance of the strategy itself.



Accident and Incident Documentation	YES	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	YES	YES
Staff and Security Equipment	NO	NO	YES	NO	NO	YES	YES	NO	YES	NO	NO	YES	YES	YES
Management Commitment	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	NO	YES	YES
Specialized Training for Workers	NO	NO	NO	NO	YES	NO	NO	NO	NO	YES	NO	NO	YES	YES
Training Program for Management	NO	NO	NO	YES	NO	NO	NO	NO	NO	YES	NO	YES	YES	YES
Mutual	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES
Safety Incentives	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Percentage of presence	14%	0%	14%	14%	14%	29%	43%	14%	29%	29%	14%	29%	71%	86%
Group average accident rate	14,36	13,20	12,67	11,97	11,19	11,08	10,50	9,99	9,94	9,88	9,87	8,18	7,27	6,25
Distance to average accident rate	19%	10%	5%	-1%	-7%	-8%	-13%	-17%	-17%	-18%	-18%	-32%	-40%	-48%
Record Count	85	2066	199	67	320	45	37	64	47	33	44	43	36	70
Percentage of Records	2%	55%	5%	2%	9%	1,2%	1,0%	1,7%	1,3%	0,9%	1,2%	1,1%	1,0%	1,9%

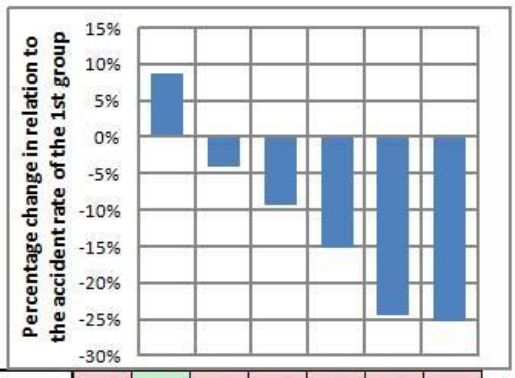
Figure 3 - Strategies with at least 30 records

Using a similar analysis approach, it is possible to assess the impact of individual practices. Strategies 1, 3, 4, 5, 8 and 11, from Figure 3, have only one prevention

practice each, and they are displayed in Figure 4 to analyse the individual impact, compared with companies that do not do anything.

Companies where the only practice was "Documentation of accidents and incidents" had accident rates higher than companies without any practice. This is consistent with the definition of the practice; as the documentation of accidents and incidents usually begins after there have happen a lot or a very serious accident, to determine their causes. In that sense, we can say that this is a practice of reaction rather than prevention.

In second place, "Staff and Safety Team," has an impact of only 4% of the accident rate compared with companies without any practice. As in the previous case, this is because many of the activities that comprise this practice correspond to the preparation of plans and safety programs, which are just the first steps to reduce the number of accidents in a workplace. "Training Program for Directors" had only a 9 % impact on the accident rate. While the practice "Specialized training for workers" appears in fourth place, and reduced by more than 15% accident rate. This shows that training those that carry out the activities has higher impact than training of those who run them.



Accident and Incident Documentation	NO	YES	NO	NO	NO	NO	NO
Staff and Security Equipment	NO	NO	YES	NO	NO	NO	NO
Management Commitment	NO	NO	NO	YES	NO	NO	NO
Specialized Training for Workers	NO	NO	NO	NO	YES	NO	NO
Training Program for Management	NO	NO	NO	NO	NO	YES	NO
Mutual	NO	NO	NO	NO	NO	NO	YES
Safety Incentives	NO	NO	NO	NO	NO	NO	NO
Percentage of presence	0%	14%	14%	14%	14%	14%	14%
Group average accident rate	13,20	14,36	12,67	11,97	11,19	9,99	9,87
Distance to average accident rate	10%	19%	5%	-1%	-7%	-17%	-18%
Record Count	2066	85	199	67	320	64	44
Percentage of Records	55%	2%	5%	2%	9%	1,7%	1,2%

Figure 4 – Analyzing the impact of individual practices

Fifth and sixth place are the practices "management commitment" and "Mutual Safety," respectively, which reduced about 25% accident rate. This significant reduction can be explained in part because companies that adopt this type of commitment from the administration or management are those that do have a low accident rate, and work to reach the target zero accidents, with a strategic vision of the company. It is noteworthy that in the Mutual practice there are implementation activities as that lead to certification of practices which is a clear indication that the company has safety as one of its strategic goals.

In summary, this simple analysis identified practices and strategies that have a greater impact and can support the design on more effective an economical safety management strategies.

Classification Tree Approach

As a method to support the design of optimal strategies, you can keep identifying new practices that combined with other already in place will have a higher impact until an optimal solution is found for each company. The method described before can be implemented using the classification tree method using the exhaustive CHAID algorithm. This method allows us to divide the sample into two nodes, according to the presence and absence of the practice that generates the most significant difference between the average accident rates of both nodes, and so on until we find statistically significant differences. This will not only make sure that there are statistical differences between the accident rate for different nodes, but also allows us to identify routes of application of the identified practices, which in turn allows us to measure the marginal impact of each of these for different combinations.

The analysis provides the classification tree shown in Figure 5 as output: a tree of twelve nodes, with seven terminal nodes, which corresponds to a total of seven possible routes. For analysis purpose, we will use the same graphic format used previously, except that they include the percentage of presence for each of the practices that the algorithm used in each node.

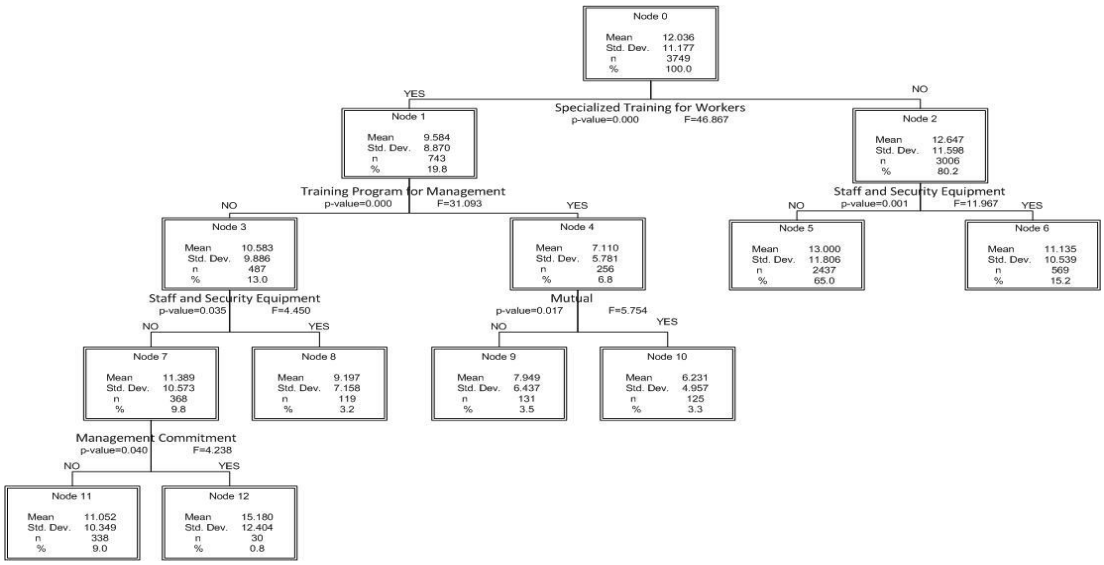


Figure 5 - Classification Tree using exhaustive CHAID algorithm

Some preliminary observations from examining figures 5 and 6 are important before proceeding with the main analysis. The 7 nodes represent 100% of all records in the present study. The worst strategy represented 0.8% of total records, and had a high percentage of practices present (48%), this can be probably attributed to a reaction to poor safety performance from companies. The second worst strategy represents the 65% of total records; therefore, the two worst strategies are present in 2/3 of the projects studied.

Similar to the analysis from Figure 3, as higher percentage of practices present, the lower the accident rate. The first node can be considered a singularity with regard to the presence of practices, considering that only represents 0.8 % of the records. Therefore, the worst node has a 4% of practices implemented, while the best node has 92%, the higher percentage. However, as for the previous analysis, this growth is not completely linear, and we find nodes that have a more presence of practices and have a worse accident rate than the next node. This relationship shows again that, for intermediate ranges, the right combination is more important than the number of practices.

Accident and Incident Documentation	63%	7%	33%	4%	54%	43%	70%
Staff and Security Equipment	NO	NO	YES	NO	YES	60%	94%
Management Commitment	YES	6%	36%	NO	55%	53%	83%
Specialized Training for Workers	YES	NO	NO	YES	YES	YES	YES
Training Program for Management	NO	5%	29%	NO	NO	YES	YES
Mutual	23%	3%	21%	2%	36%	NO	YES
Safety Incentives	3%	0%	2%	0%	7%	4%	6%
Percentage of presence	**48%**	**4%**	**37%**	**18%**	**59%**	**60%**	**92%**
Node average accident rate	**15,18**	**13,00**	**11,14**	**11,05**	**9,20**	**7,95**	**6,23**
Distance to average accident rate	**3,14**	**0,96**	**-0,90**	**-0,98**	**-2,84**	**-4,09**	**-5,80**
Record Count	**30**	**2437**	**569**	**338**	**119**	**131**	**125**
Percentage of Records	**0,8%**	**65,0%**	**15,2%**	**9,0%**	**3,2%**	**3,5%**	**3,3%**

Figure 6 - Average accident rate terminal nodes with exhaustive CHAID algorithm

General Aspects of the Database analysis

From the analysis of all the records, it was possible to observe a decrease in average accident rate over the years, as well as a decrease in the dispersion of the data. Since the industry average is above the median of the data it is necessary to focus on worst performers so that the impact of prevention is more effective. These companies generally have only a few workers, since there is some correlation between the size of the company and the accident rate. This implies that in order to attack the worst-performing companies, specialized programs for smaller companies should be developed.

It was also noted that there is a huge difference in the way in which companies face the prevention of accidents before and after having suffered an accident, which is reflected in the percentage of companies not engaged in prevention when they have suffered accidents (55.11%) and when they have not been affected (96.04%). This

results suggests that the decision to initiate prevention activities in a company often occurs in a reactive rather than a proactive manner. However, this hypothesis was not fully analyzed in this study, it will studied more thoroughly in the future analyzing the initial dates of prevention activities and the date of occurrence of severe accidents to determine the reactivity of prevention companies. This could be the first step in a study o historical series of prevention and accidents, to understand the dynamic impact of safety management on company performance.

SUMMARY AND CONCLUSIONS

The focus of the paper has been in the data analysis from the SM database, with emphasis on the analysis method and the prospects of future research in this line. Seven practices with statistically significant impacts on safety rates were identified and selected for further analysis. Most of these practices are related with lean production practices and the discussion of this relationship is the subject of another paper referred in the text. The extended research methodology of this research includes the implementation of a survey that is designed to identify management practices, including "Lean Management Practices", that are present in the companies studied, to incorporate this additional aspects in future analysis. The conclusions below are related to the discussion of results of the analysis of the data described in the paper and to the limitations and future development of this research.

From the analysis of the data it was found that even though the number of prevention activities had a statistically significant correlation with accident rate, the analysis in the graphical strategy format showed that this factor itself provided only a partial explanation. Significant differences occurred for certain ranges once a certain number of practices are reached. At a certain point, the marginal contribution of adding more prevention practices is virtually zero. In future work the authors will explore this relation for companies of different characteristics.

The analysis of the combined effect of prevention practices (safety management strategies), showed that more important than the number was the choice of the right combination. This analysis approach can bring significant savings to companies by contributing to the design of effective strategies that can lead to best results at a minimum cost. Similarly, Safety Mutuals can benefit themselves and their associates by developing highly effective prevention strategies with the least cost. Moreover, these methods can help to determine the order of implementation of different practices, so as to achieve greater impact at first, and then continue with the higher marginal impact.

The strategy analysis method proposed seems to be an attractive method to design safety management strategies if the appropriate data is available. Because of the space constraints, one of the features that were not discussed in the paper is that the method can be used to perform individual analysis for a company considering its particular characteristics: company size, type of business, type of projects, or any other attribute or combination. This eventually allows the development of custom designed programs. Applied in companies which have massive data on their prevention programs this method could enable them to measure the impact on safety of every new management initiative.

This method also allows for analyzing individual factors of a safety program, or any unconventional prevention activity to be implemented, provided that there are

sufficient data for the analysis. Future work will pursue the development of software that integrates data capture with this analysis methodology to support the design of safety management strategies for companies and projects according to their specific characteristics and needs.

Unfortunately, the database used did not include data on important aspects of companies' own prevention activities or management practices (i.e. lean management practices), making it difficult to obtain a more comprehensive understanding of the impact of safety management strategies in companies. It will be essential to extend the data capture of the SM through a complementary system such as the survey developed by our research team, in order to assess the full picture of management practices within each company, including the impact of lean practices on safety performance.

ACKNOWLEDGEMENTS

The authors want to thank the Safety Mutual of the Chilean Chamber of Construction for their support to this research.

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