FINDING DIFFERENCES AMONG CONSTRUCTION COMPANIES MANAGEMENT PRACTICES AND THEIR RELATION WITH PROJECT PERFORMANCE

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ABSTRACT

The performance of construction companies is linked to the performance of their projects, as their financial success as well as the satisfaction of their clients depends on it. However, most studies of construction companies' performance consider mainly the corporate aspects but not the performance they achieve in their projects that are a result of their management practices. A key issue is determining the differences among management practices used by construction companies that provide them with a competitive advantage. This is the purpose of this study. To achieve this goal, nine construction companies participated in this collaborative benchmarking study. There is a group of management practices that differentiate the investigated construction companies. The results highlight the relevance of the management of information and communication and the importance of lean management practices as the tools for analysis and planning or to improve processes. Construction companies' managers should consider these differentiating elements as a path to achieve a competitive advantage.

KEYWORDS: Construction companies; Correlation; KPI; Management practices; Project performance.

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INTRODUCTION

The performance of construction companies is tied to the performance of their projects (Gann and Salter 2000): their financial success depends on it, as well as the satisfaction of their clients (Luna-Villarreal et al. 2017). Furthermore, many of the business processes are aimed at facilitating productive (in this case, construction) processes (Radosavljevic and Bennett 2012). However, the assessment of construction companies' performance considers, most of the time, only corporate aspects, not the performance they achieve in their projects as a result of their management practices (Luna-Villarreal et al. 2017). Because the construction industry is project-oriented, it is a key issue to measure project performance related to company performance (Gann and Salter 2000; Yu et al. 2007).

Within this scenario, benchmarking is a technique commonly used as a reference point for measurement and comparisons among construction companies. Benchmarking can be applied to measure and compare every kind and nature of processes in the involved companies. Particularly, collaborative benchmarking ensures improvement for the participating members through mutual learning (Ramirez et al. 2004). Benchmarking intangible aspects such as management practices have become of interest in many industries (Bloom and Van Reenen 2007) and in the construction industry (Shan et al. 2011). Management practices can make a difference in obtaining better performance in construction companies (Bogan and English 2014). A practice is a way of doing something that is the usual or expected way in a particular organization or situation (Oxford Universty Press 2015). Considering this definition, in this research, a management practice is a process or method that is usually applied in the management of a construction company. According to the Construction Industry Institute (CII hereafter), a "best" practice is a process or method that causes enhanced project performance (CII 2011); thus, there is an implicit relationship between practices and performance in the construction industry (Lee et al. 2005; Cha and Kim 2017).

Nevertheless, an important limitation so far is that the evaluation of qualitative measures requires considerable time and effort and may have a direct impact on the accuracy of the evaluation results (Jin et al. 2013). Much of the literature about management practice evaluation in the construction industry has traditionally been case-study and survey based (Jin et al. 2013; Nasir et al. 2012; Shan et al. 2011). In this case, it is necessary to use statistics to find the differences between the respondents. Additionally, benchmarking systems usually work on the basis of a fixed number of management practices previously identified as the best (Bloom and Van Reenen 2007; CII 2011; Kim 2014), which restricts their use and accessibility to relevant data defined by the users. Benchmarking should evolve to a more comprehensive and more flexible form to provide better results for its participants (Albertin et al. 2015). Best practices could be picked from a common set used by the companies that participated in the benchmarking, revealing the essential differences between firms that provide competitive advantage (Porter 1998).

Hence, the goal of this study is to find the differences among numerous management practices inside a benchmarking group of construction firms by using statistical tests to identify those best management practices that enhance performance. To accomplish this goal, this paper is structured in as follows: the next section addresses the research method; later, the management dimensions and practices are outlined and the survey explained; the fifth section of the paper analyses and discusses the results of the research; and finally, the conclusions present the contributions, limitations and recommendations.

RESEARCH METHOD

Case selection

The present study was developed during a one-year period, in nine construction companies operating in Chile; they make up the sample set of this research. The companies were part of a benchmarking exercise within the "Building Excellence Group," a collaborative group of companies that develop applied research with the Center for Excellence in Production Management – GEPUC. The benchmarking group had already been working together to launch this research project. A collaborative benchmarking refers to a group of firms sharing knowledge in the hope to improve based on what they learn from each other (Lankford 2002). The advantages of collaborative benchmarking between construction companies have been described before (Costa et al. 2006). This methodology has been cited as an efficient way of sharing high-quality information and motivating learning (Albertin et al. 2015).

Overall Approach

To achieve the research goal, a literature review was developed to identify the most commonly used management practices and key project performance indicators. The research was carried out in the Web of Science and Scopus databases, over a period ranging from 1990 to present. The keywords used were "benchmarking", "management practice" and "performance indicator", combined with "construction industry", "construction project", and "construction company." They were combined into different search strategies aiming to obtain as many relevant papers as possible. After removing duplicate articles, the publications retrieved were filtered for relevance, by reading and analyzing them. The articles published on management practices in companies are scarce, but the literature on project management tools and indicators is abundant because they are considered more useful than their business counterparts (Delgado-Hernández et al. 2017; Luna-Villarreal et al. 2017). In this way, 95 relevant papers on performance indicators were found, whereas only 40 papers on management practices were obtained.

In addition, the literature review also considered documents based on management practices that are applied in industry by consensus (e.g., ISO —International Organization for Standardization— and ASQ —American Society for Quality— on quality management). The main referent for this research was a previous work of the authors (Ramirez et al. 2004), which contains a proposal of the main management practices of the Chilean construction industry; therefore, the research shown in this paper builds on that of Ramirez et al. (2004).

The literature search of the most common groups of practices used in management resulted in a list of construction management practices. Most management practices have to do with procedures, regulations, leadership, incentives, innovation, coordination, planning and information among other aspects (Daft 2012; Zimmermann and Eber 2014). Indeed, they were evaluated by a survey questionnaire, which was later used to collect information on the management practices of the nine companies mentioned above. According to Bloom and Van Reenen (2010), obtaining responses from employees at different levels of the firm's hierarchy helps to identify systematic differences in responses; personnel with decision making capacity from the CEO to the field engineers were involved. These data were collected with a survey platform and the responses for every dimension were transformed to a weighted score. Analysis of variance (ANOVA from now on) and Tukey's test were applied to the management practice scores by dimension to identify significant differences between management practices.

Regarding project performance, the research team took advantage of the same nine companies. First, semi-structured interviews were conducted with 21 project managers at these nine companies to obtain the nine final indicators out of the 23 original ones. Later, 41 projects from these nine companies were selected for further document analysis. These projects ranged from USD $5 million to $100 million, including residential buildings as well as industrial facilities. The companies selected the projects under the following criteria: projects that had started at least three months before and were within three months of closing, to avoid the bias of the beginning or ending of the projects. A three-month report from these projects for every key performance indicator (KPI from now on) was produced. The median value of every KPI of every project in each company became an average rank for use as a performance indicator.

Descriptive statistics were obtained for both the management practices and performance indicators. The Spearman correlation was applied using scores from differentiated management practices and KPI medians. The outcomes were grounded in the body of knowledge to highlight the contributions of this research. The research method is summarized in Fig. 1.

<FIGURE 1 HERE>

Management practices

Even though the topic of "best" management practices in the construction industry has not been researched in depth (Cha and Kim 2017; Delgado-Hernández et al. 2017), there are three general proposals in this field that have to be taken into account. First, the Construction Industry Institute (CII 2011) has been working on this topic since the nineties; the institute has proposed a framework listing best management practices, which collects voluntary data from projects all over the world but is mainly located in the U.S. (CII 2011; Kim 2014). Second, Ramirez et al. (2004) suggested fifteen groups of management practices for the Chilean construction industry. A final contribution worth mentioning is that of Cha and Kim

(2017); these authors link the chosen best practices to South Korean building projects. These three contributions use survey data in order to assess the benefits of a management practice.

To choose the relevant management practices, in this paper, the point of departure was the previous work of the authors described in Ramirez et al. (2004). This proposal was completed and improved with the other two proposals (CII 2011; Cha and Kim 2017), as well as with many different individual management practices found in the literature review. Later, the management practices were discussed in four workshops with project managers to identify the most important practices from the pool found in the literature. Those considered relevant and of common use (133) were selected by the managers of the companies for this research. The final list of practices and sources considered are displayed in Table 1.

<TABLE 1 HERE>

From the original fifteen groups of practices developed by Ramirez et al. (2004), twelve were retained: Quality, Communication and Information, Costs and Schedule, Leadership, Corporate Goals, Organizational Change, Planning and Programming, Production, Human Resources, Relations with Owner, Health and Safety, and Technology. Regarding the other three, two were merged into Supply, whereas Relationships with Designers was not considered worthy by the participants in the workshops. Furthermore, two additional groups were acknowledged: Risk (PMI 2013; Cha and Kim 2017) and Innovation (Pellicer et al. 2014; Yepes et al. 2016).

The authors, in collaboration with the top managers of the participating companies, developed a survey with 133 questions (one for each management practice), distributed as follows: Quality (14), Communication and Information (7), Costs and Schedule (8), Supply (9), Risk (8), Innovation (15), Leadership (6), Corporate Goals (5), Organization and Change (9), Planning and Programming (7), Production (8), Human Resources (19), Labor Health and Safety (11), Relationship with the Owner (5), and Technology (2). To capture the practice implementation perception, answers were associated with a 5-point Likert qualitative scale of response (Nunnally and Bernstein 1994; Boone and Boone 2012), ranging from 1 (strongly disagree) to 5 (completely agree). To prevent people from answering questions concerning matters of which they were not aware, a “do not know / does not apply” option was available. Only scaled answered questions were used to calculate the weighted average to score the practices using this formula:

$$Score = \frac{\sum_{i=1}^{n} answer\ score_i}{5\ n}$$

where n = number of answers to each question (Nunnally and Bernstein 1994; Boone and Boone 2012).

A pilot survey was tested with 20 project managers. Once the questionnaire was tuned considering the feedback received, surveys were administered via the Internet to the management personnel of the companies—from the CEO down to project managers. The survey administration included issues such as confidentiality and anonymity, timing and notifications. To keep the survey on schedule, reminders were sent to the survey participants via the company CEO. A total of 1,602 people participated in the management practice survey.

To estimate the reliability of the management practice survey, the Cronbach test was applied and tested. Later, to find significant differences between companies’ management practices, analysis of variance (ANOVA) was applied to all management practice scores for each management dimension. ANOVA uses a single hypothesis test to check whether the means across many groups are equal. The null hypothesis (H0) is that “the mean outcome is the same across all groups”, whereas the alternative hypothesis (HA) is that “at least one mean is different”. The ANOVA method calculates the F statistic: if the means of the data series are similar, then F has values less than 1; if the means are different, then F has values greater than 1. The more different the means are, the greater the value of F is. Additionally, a p-value equal to or less than 0.05 is considered to reject the H0 (Cohen et al. 2011; Boone and Boone 2012). ANOVA was performed to test the hypothesis that several means of the management practice data series among the 15 groups of management practices of the nine companies were different. ANOVA reveals whether the results are significantly different overall, but it does not determine exactly where those differences lie. When only two practices' means were compared, only ANOVA is needed to find significant differences.

After running ANOVA and with evidence that the means are likely not all equal, Tukey's test determines which specific groups' means are different by comparisons with each other (Evans 2012). This test compares all possible pairs of means. Tukey's test was applied as a post hoc analysis to find management practice means that were significantly different from each other to show which ones were truly different inside each management practice group. To provide a summary of the sets of groups generated, the Compact Letter Display method (Greenwood and Banner 2017) was used to generate and report the results of the Tukey's tests. Groups with the same letter are not detectably different (they are in the same set), and groups that are detectably different have different letters (they are in different sets). Groups can have more than one letter to reflect an overlap between the sets of groups, and sometimes, a set of groups contains only a single letter. If the groups have the same letter, this does not mean they are the same, only that there is no evidence of a difference for that pair.

Project Performance Indicators

An in-depth literature review of the KPIs frequently used for performance measurement at the project level and benchmarking resulted in an initial 23 common KPIs (Cox et al. 2003; Bassioni et al. 2004; Beatham et al. 2004; Radujković et al. 2010; Nasir et al. 2012; Hwang et al. 2013; Yeung et al. 2013; Zavadskas et al. 2014; Yun et al. 2016; Omar and Fayek 2016; Luna-Villarreal et al. 2017; Cha and Kim 2017; Lingard et al. 2017; Jonsson and Rudberg 2017). In this case, there may be too many indicators; for example, the Construction Industry Institute (CII 2011) considers only six: Cost, Schedule, Changes, Accidents, Rework, and Productivity, whereas most of the sources proposed a range from a single one (Hinze et al. 2013) to more than ten (Ramirez et al. 2004; Roberts and Latorre 2009). Some authors (Yeung et al. 2013; Dejaco et al. 2017) proposed a combined index to measure the performance of a construction project.

Interviews with 21 managers were carried out to prioritize nine out of the 23 initial KPIs. The final nine KPIs were Cost Deviation, Schedule Deviation, Accident Frequency, Accident Gravity, Planning Effectiveness, Constraint Release, Quality, Productivity, and Contract Bid Change. Planning Effectiveness and Constraint Release were included because the companies had previously implemented several lean construction tools, and these two indicators were also useful to measure the effectiveness of such implementation. Planning Effectiveness is an indicator generally used in control planning to measure the ratio between fulfilled activities over scheduled activities (Ramirez et al. 2004; Sarhan and Fox 2013). A more specific lean indicator is Constraint Release, which measures the relationship between the detected constraints over the released constraints in a certain period of time (Seppanen et al. 2015; Wang et al. 2016). The final nine KPI selected by the project managers are detailed in Table 2, as well as the formulas used to compute them.

<TABLE 2 HERE>

Additionally, in conjunction with these 21 project managers a document was designed to be completed monthly with data for these nine KPIs and reported to the research team. For three months, the reports were completed by the project managers for every construction project. The median of the KPIs of all the projects of each company was used as a performance indicator. Those medians were converted into an average rank to overcome the differences of magnitudes and units of each of them. To obtain the average rank, an order number was assigned to each value: the smallest value is assigned a "1", the second smallest a "2", and so on, to the largest. If there were repeated values, they were assigned their mean order number. For example, for Contract Bid Change (see Table 6 later), the same value (1.00) was repeated in positions 7 and 8; therefore, instead of assigning them "7" and "8", "7.5" was assigned to both. For assessing the performance of a construction company, the KPIs of their construction projects were obtained during the same periods in which their management practices were measured.

Correlation Analysis

Correlation is used to investigate the relationship between two variables (Cohen et al. 2011; Evans 2012). A correlation analysis was applied to the management practice scores that were significantly different, as well as the performance of the projects represented by the KPI medians. Practices that did not have significant differences were omitted because they did not provide information when establishing whether a company had practices different from the others. Previously, the two sets of results had been converted into average ranks as explained previously. Considering that there were little data in the two series (9), it was decided to apply the non-parametric Spearman correlational analysis. Spearman's r is the correlation coefficient of the ranked data. Only strong ($0.6 \leq r < 0.8$) and very strong ($r \geq 0.8$) correlation strengths based on the absolute values of Spearman's r were assumed to be important. Additionally, the corresponding significance of the pairwise p-values equal to or less than 0.05 were considered an indication of a highly significant relationship, since a small p-value is an indication that the null hypothesis (non-correlation) is false (Cohen et al. 2011; Evans 2012). The statistical software R (version 3.1.2) was used to obtain the r and p-values (R Foundation 2015).

RESULTS AND DISCUSSION

Management Practices

As result of the survey test run, values higher than 0.8 were obtained for Cronbach's alpha; this is considered a good quality indicator of a survey (Nunnally and Bernstein 1994). Later, the main survey campaign was developed, and the scores of 133 practices for each of the nine companies were obtained. Several practices had fairly similar scores among the nine studied companies. The survey scores obtained for every management practice (by company) are detailed in the Supplemental Data section (Table S1). The response rates obtained and the errors for 95% confidence levels are detailed in Table 3. Error values were calculated by using the sample formula for a finite population (Cohen et al. 2011; Evans 2012):

$$n = [(z^2 * p * q) + e^2] / [e^2 + z^2 * p * q / N]$$

where: N is the population; the Z score = 1.96 squared (if the confidence level is 95%); p = the expected proportion (in this case 50% = 0. 5); q = 1-p (in this case 1-0.50 = 0.50); and e = the error level.

<TABLE 3 HERE>

As shown in Table 3, it was possible to achieve high response rates in companies with few employees. Nevertheless, for large companies the response rates were lower. Anyway, they were sufficient to achieve good levels of confidence and errors.

After applying ANOVA and for a level of significance of 5%, there were differences among the management practices ($p < 0.05$), indicating that at least one of the average values of the scores were different from the others for each of the management dimensions. Table 4 shows the results for the 15 management dimensions obtained from the nine construction companies.

<TABLE 4 HERE>

Since F > 1.0 and p < 0.05, the alternative hypothesis was accepted, and it was assumed that there were significant differences among the means of the scores of the management practices in 14 out of the 15 groups. However, a significant difference between the means of the data sets for the Corporate Goals dimension ($F(4, 40) = 1.918$; $p = 0.126$) was not found.

Post hoc comparisons using Tukey's test noted that the mean scores for 25 out of the 133 evaluated management practices were significantly different. In Figure 2, the results of the multiple comparison Tukey's test are provided with their means and the Compact Letter Display method results (Greenwood and Banner 2017); unique letters highlight different management practices among the management dimensions. Taken together, the results suggest that some management practices really do have a different implementation level inside the construction firms, as reported by the surveyed personnel. Specifically, these results suggest that the 25 management practices shown in Table 5 make a significant difference among the construction firms' management.

<FIGURE 2 HERE>

The Tukey's test results confirmed that there were no significant differences among the companies' corporate goals management practices. Otherwise, the use of incentives to reward performance and promote the contributions of employees to the company appears in several of the practices that distinguish the construction companies analyzed. Tools for communication and information management are highlighted in Table 5.

<TABLE 5 HERE>

Project Performance Indicators

The median values of the KPIs from each company group of projects are listed in Table 6. A detailed list of those ranked KPIs is provided in Table 7, where the letter C stands for company. The companies present different rankings according to their KPIs. These results indicate that there is no equal performance in the different aspects measured by the indicators. Although every KPI in isolation does not provide a balanced view of the project's performance, success is desirable in each of them (Kagioglou et al. 2001).

<TABLE 6 HERE>

<TABLE 7 HERE>

Correlation Analysis

After converting to the average ranks, the KPI series as well as the significant different management practice scores, the Spearman correlation was applied to the data series. The results are shown in Table 8.

<TABLE 8>

Only seven out of the 15 management groups of practices applied in the companies appear related to the performance of their projects: Relationship with the Owner, Costs and Schedule, Human Resources, Production, Risk, Organizational Change, and Communication and Information. Perhaps the other groups have more of an administrative function in the company instead of a technical function needed for a project's production (Campero and Alarcón 2014).

Regarding the Relationship with the Owner, the form of selection and award to the contractors has an important relationship with easing the execution of the planned activities, which is a determinant for good performance of a project (Leal and Alarcón 2010; Pellicer et al. 2016). However, the introduction of new forms of contracts could be hindering the release of restrictions because innovations often produce counterproductive effects in their early stages and requires management support and resource allocations to deliver benefits (Pellicer et al. 2014; Yepes et al. 2016). Lean production practices, as well as the use of cost and schedule management tools, have a positive relationship with a project's cost deviation and quality (Maturana et al. 2007; Ballard 2008; Issa 2013). The positive impact of cost and schedule management on the quality indicator that measures rework seems to also have a logical consequence on project costs (Leal and Alarcón 2010; Aziz et al. 2013). Moreover, lean production management practices, such as inventory reduction by ordering small lots, appear to have yielded good results in two key aspects of project performance: accidents and rework reduction (Seppanen et al. 2015; Wang et al. 2016; Alarcon et al. 2016).

Similar positive effects have been reported (Leal and Alarcón 2010), since it avoids material deterioration (Aziz and Hafez 2013), and well-planned production reduces pressure on workers and contributes to improved safety (Alarcón et al. 2016; Lingard et al. 2017). Risk management is not a systematic practice among construction companies (Serpell et al. 2017); however, those firms concerned about a high implementation of this dimension have a positive correlation to planning in their projects also by using simulation methods, which seems to be a best management practice. On the other hand, establishing risk policies and goals, which maybe a reaction to accident severity, is depicted by a negative correlation. Nonetheless, the application of new communication tools such as the use of BIM is another management practice that has gradually advanced in construction companies (Lee et al. 2014; Azhar et al. 2015). As seen here, there was a high positive relationship with the quality of the projects, as these tools facilitate coordination by improving communication among those involved (Lee et al. 2014). Change management information is a capital issue since it incentivizes the project stakeholder's participation in solutions (Shoura and Singh 2008); in the projects studied here it was related to project quality improvement. Finally, communicating company policies to new personnel as a human resources management practice emphasizes the importance of involving staff from the moment they enter the company, and their relationship with project costs may be due to the commitment and learning that is obtained through communication (Yitmen 2012). Overall, a higher development of management practices appears to be associated with better performance in almost all cases, as found in previous studies (Ramirez et al. 2004; Cha and Kim 2017).

CONCLUSIONS

This research aimed to find the differences between the management practices of construction companies participating in a collaborative benchmarking exercise and their relationship with project performance. The application of statistical techniques such as ANOVA and Tukey's test, based on the covariance analysis of the data series, allowed the distinguishing of those management practices that significantly differed among the companies. After the analysis of correlation, it was seen that those differentiated management practices were significantly related to better performance of their projects, except in aspects such as the labor accident ratio, which seems to depend on the actions taken in the project more than the corporate management practices.

By identifying the practices that constitute the essential differences between companies and the relationship to their performance, this paper provides performance measures that include not only the business management but also the project performance, offering a tool for the development and maintenance of corporate competitive advantages. In this study, it was established that the number of management practices is not a differentiating element among companies but their level of implementation is. Therefore, out of 133 common practices, only 25 business management practices have been implemented at a level that represents a difference; out of these, only nine were shown to be related to the performance that companies obtain in their construction projects. This implies that the number of practices that the companies implement is not related to the performance of their projects but that some of these practices do not seem to have any relationship to the main product of the construction companies: their projects.

Among the group of management practices that differentiate the investigated construction companies, the results highlight the relevance of lean management practices as the tool for analysis and planning or to improve processes in project performance. Additionally, the importance of the management of information and communication in many of the management dimensions, as perceived by the members of the company, and their positive relationship to a project's KPIs must be noted. These findings should be considered by construction companies' managers as differentiating elements that could yield a competitive advantage, as evidenced by the correlation of the management practices with a company's performance.

Whether the fairly close values obtained in the evaluation of management practices was the result of the design and application of the surveys is still to be explored or confirmed, as well as whether those results in fact correspond to a group of companies that have advanced in a common way through collaboration; consequently, their common management practices have a similar level of development. The results obtained with the management practices of the corporate goals seem to indicate this similarity.

Despite the significant amount of data reported both for management practices and project KPIs, the main limitation of this research is the small number of companies investigated, which limits the possibility of generalizing the findings. Nevertheless, it allows obtaining a realistic description of a group of construction companies that are part of a larger reality that must be investigated regarding the influence of corporate management practices on the performance of their construction projects. In addition, the point at which project management practices have a greater influence on project performance than the management practices of the company also merits future research.

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SUPPLEMENTAL DATA

Table S1 is available online in the ASCE Library (ascelibrary.org).

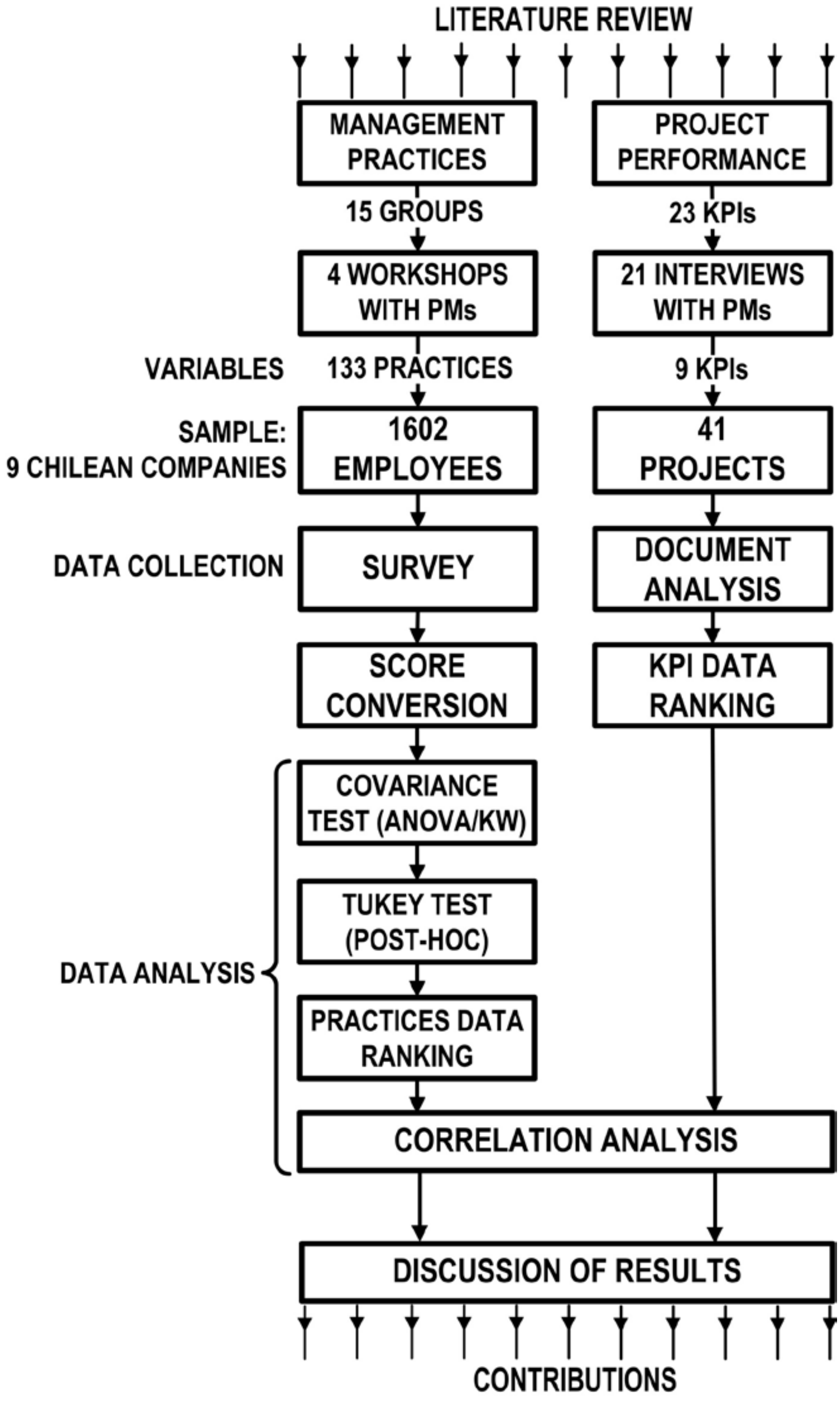
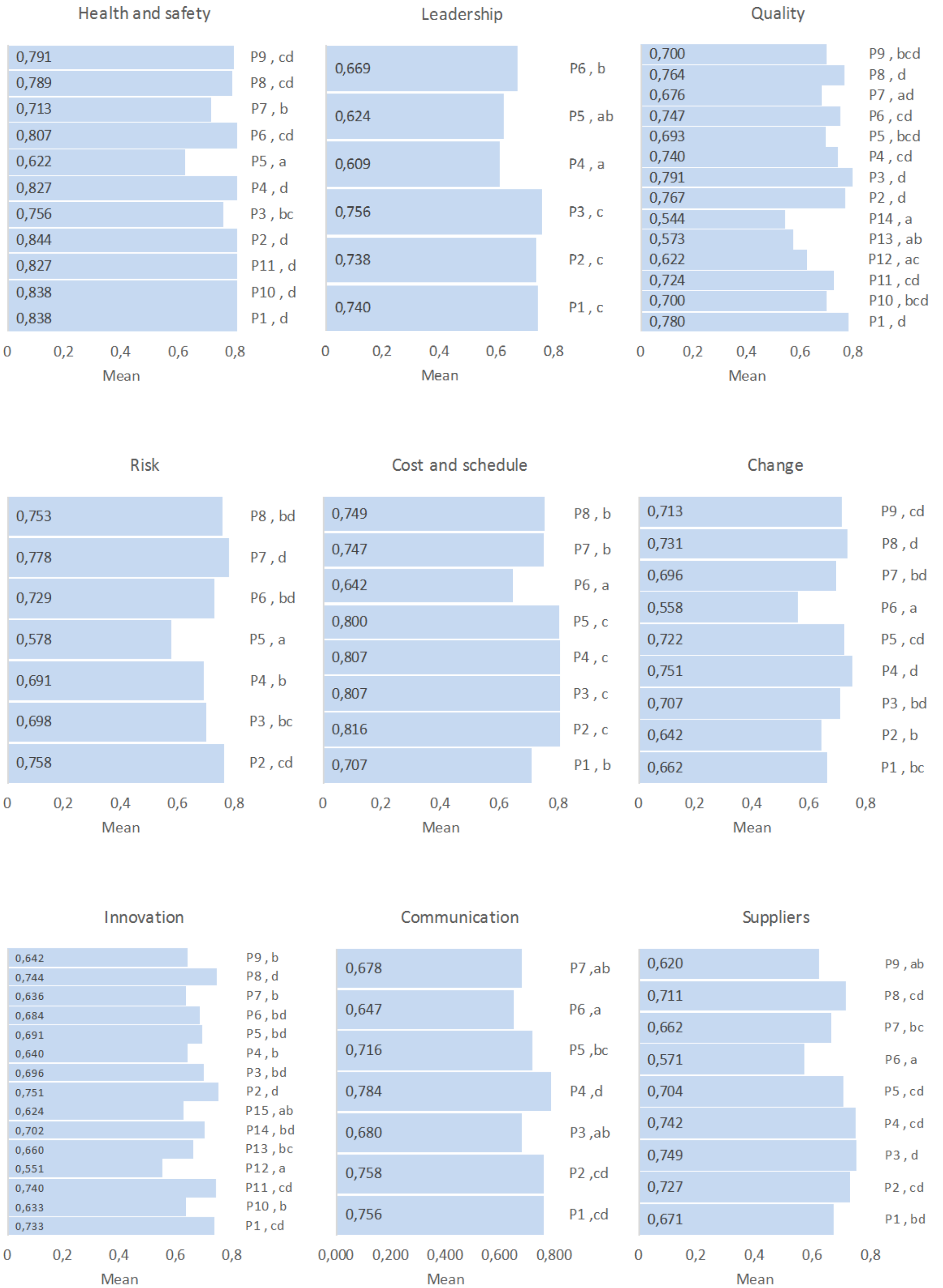


Figure 1. Research method



Health and safety
0,791 P9 , cd
0,789 P8 , cd
0,713 P7 , b
0,807 P6 , cd
0,622 P5 , a
0,827 P4 , d
0,756 P3 , bc
0,844 P2 , d
0,827 P11 , d
0,838 P10 , d
0,838 P1 , d
0 0,2 0,4 0,6 0,8
Mean
Leadership
0,669 P6 , b
0,624 P5 , ab
0,609 P4 , a
0,756 P3 , c
0,738 P2 , c
0,740 P1 , c
0 0,2 0,4 0,6 0,8
Mean
Quality
0,700 P9 , bcd
0,764 P8 , d
0,676 P7 , ad
0,747 P6 , cd
0,693 P5 , bcd
0,740 P4 , cd
0,791 P3 , d
0,767 P2 , d
0,544 P14 , a
0,573 P13 , ab
0,622 P12 , ac
0,724 P11 , cd
0,700 P10 , bcd
0,780 P1 , d
0 0,2 0,4 0,6 0,8
Mean
Risk
0,753 P8 , bd
0,778 P7 , d
0,729 P6 , bd
0,578 P5 , a
0,691 P4 , b
0,698 P3 , bc
0,758 P2 , cd
0 0,2 0,4 0,6 0,8
Mean
Cost and schedule
0,749 P8 , b
0,747 P7 , b
0,642 P6 , a
0,800 P5 , c
0,807 P4 , c
0,807 P3 , c
0,816 P2 , c
0,707 P1 , b
0 0,2 0,4 0,6 0,8
Mean
Change
0,713 P9 , cd
0,731 P8 , d
0,696 P7 , bd
0,558 P6 , a
0,722 P5 , cd
0,751 P4 , d
0,707 P3 , bd
0,642 P2 , b
0,662 P1 , bc
0 0,2 0,4 0,6 0,8
Mean
Innovation
0,642 P9 , b
0,744 P8 , d
0,636 P7 , b
0,684 P6 , bd
0,691 P5 , bd
0,640 P4 , b
0,696 P3 , bd
0,751 P2 , d
0,624 P15 , ab
0,702 P14 , bd
0,660 P13 , bc
0,551 P12 , a
0,740 P11 , cd
0,633 P10 , b
0,733 P1 , cd
0 0,2 0,4 0,6 0,8
Mean
Communication
0,678 P7 ,ab
0,647 P6 ,a
0,716 P5 ,bc
0,784 P4 ,d
0,680 P3 ,ab
0,758 P2 ,cd
0,756 P1 ,cd
0,000 0,200 0,400 0,600 0,800
Mean
Suppliers
0,620 P9 , ab
0,711 P8 , cd
0,662 P7 , bc
0,571 P6 , a
0,704 P5 , cd
0,742 P4 , cd
0,749 P3 , d
0,727 P2 , cd
0,671 P1 , bd
0 0,2 0,4 0,6 0,8
Mean

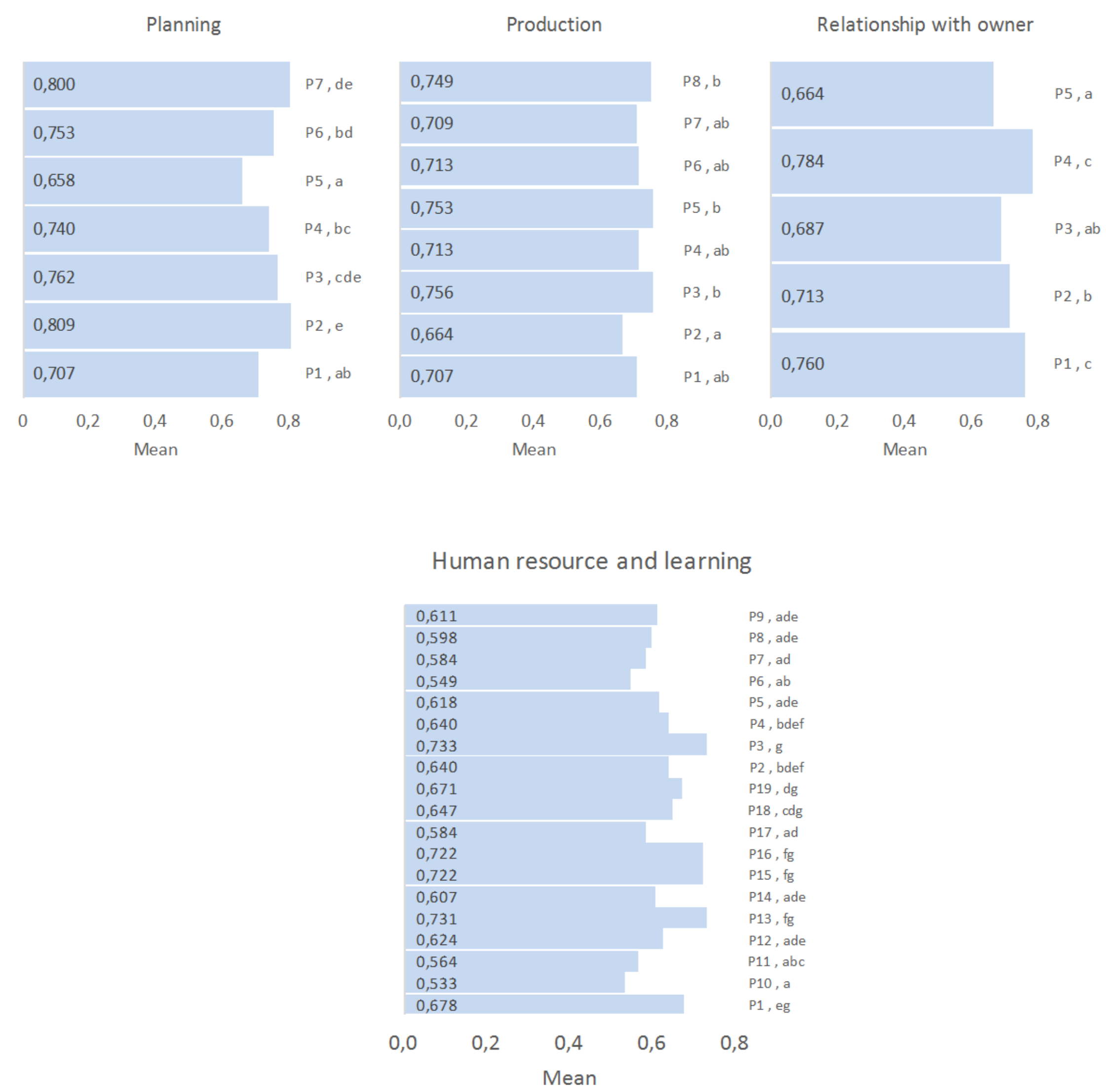


Figure 2. Results of Tukey’s test for management practices

Table 1. Literature review of management practices

Dimension	Management practices	References
Quality	Quality management system Monitoring and measuring Competence and training Quality culture	ASQ 2013; ISO 2009, 2015; Ramírez et al. 2004; Lee et al. 2014; Shaari et al. 2016; CII 2011; Cha and Kim 2017
Communication and Information	Information emission Information flow Communication channels Reception	Campero and Alarcon 2014; Dainty et al. 2006; PMI 2013; Ramirez et al. 2004; Kang et al. 2013a, b; Cha and Kim 2017
Costs and Schedule	Planning process Costs and schedule monitoring Costs and schedule analysis Continuous improvement	Campero and Alarcon 2014; Dainty et al. 2006; PMI 2013; Radosavljevic and Bennett 2012; Ramirez et al. 2004; CII 2011; Cha and Kim 2017
Supply	Suppliers selection Supplier assessment Stock management	Campero and Alarcon 2014; Maturana et al. 2007; PMI 2013; Ramirez et al. 2004; CII 2011; Jin et al. 2013; Cha and Kim 2017
Risk	Risk identification Risk assessment Risk management Risk response	Al-Bahar and Crandall 1991; Choudhry and Iqbal 2012; Hillson and Simon 2012; PMI 2013; Alarcón et al. 2011; CII 2011; Cha and Kim 2017
Innovation	Identifying opportunities Ideas choice Innovation development Innovation assessment Knowledge transfer	Winch 1998; Pellicer et al. 2014; Yepes et al. 2016; Jin et al. 2013; Cha and Kim 2017
Leadership	Ability of the led Leadership skills Leadership practices	Campero and Alarcón 2014; Giritli et al. 2013; Naoum 2001; Ramirez et al. 2004; CII 2011; Cha and Kim 2017
Corporate Goals	Strategic goals management Goals achievement	Alvarado et al. 2009; Chinowsky and Meredith 2000; Merchant 2012; Ramirez et al. 2004; Bassioni et al. 2004
Organizational Change	Information on change Adaptability to change Change management Change barriers Capacity for change	Pheng and May 1997; Ramirez et al. 2004; Shoura and Singh 2008; CII 2011; Cha and Kim 2017
Planning and Programming	Business environment analysis Objectives communication Proceedings Plan implementation Monitoring	Campero and Alarcón 2014; Ramirez et al. 2004; PMI 2013; Cha and Kim 2017
Production	Planning Production process Checking Process improvement	Arbós 2011; Ballard 2008; Campero and Alarcon 2014; Goldratt and Cox 1984; Ramirez et al. 2004; CII 2011
Human Resources	Staff management Organizational learning	Campero and Alarcón 2014; Knuf 2000; Kululanga et al. 2002; Yitmen 2012; Ramirez et al. 2004; Ngwenya and Aigbavboa 2017
Relation with Owner	Motives Procurement Communication	Ballard 2008; Ramirez et al. 2004; Campero and Alarcón 2014; Laan et al. 2012; Pellicer et al. 2016
Health and Safety	Policy Organization Application Assessment Improvement	Ramirez et al. 2004; Hinze et al. 2013;OSHA 2016; Alarcón et al. 2016; Lingard 2017; CII 2011
Technology	Complexity Technological mastery	Hong et al. 2010; Love et al. 2005; Ramirez et al.

Dimension	Management practices	References
	Technology use Technology readiness Motives Technological need satisfaction	2004; Hua 2013; Jin et al. 2013; Cha and Kim 2017; Delgado-Hernández et al. 2017

Table 2. Key performance indicators (KPIs)

Item	KPI	Formula(s)
Cost	Cost deviation	$CD = \frac{(\text{Real cost} - \text{Budget cost}) * 100}{\text{Budget cost}}$
Schedule	Scheduled deviation	$SD = \frac{(\text{Real advance} - \text{Scheduled advance}) * 100}{\text{Scheduled advance}}$
Safety	Accident frequency	$FI \frac{(\text{Disabling accidents}) * 10^6}{\text{Work hours}}$
	Accident severity	$GI = \frac{(\text{Lost days}) * 10^6}{\text{Work hours}}$
Planning	Planning effectiveness	$PPC = \frac{\text{Fulfilled activities} * 100}{\text{Scheduled activities}}$
	Constraint release	$CR = \frac{\text{Released constrains} * 100}{\text{Total constrains}}$
Building	Quality	$Qi = \frac{(\text{Number of rework orders } * 10^6)}{\text{Work hours}})$
	Productivity	$PT = \frac{\text{Actual labor cost}}{\text{Budgeted labor cost}}$
Project scope	Contract bid change	$CBC = \frac{\text{Final projected sale contract}}{\text{Initial sale contract}}$

Table 3. Survey response rates and confidence levels

Company	Surveys	Responses	Response rate	Error for the 95% confidence level
C1	72	42	58.3%	9.8%
C2	36	32	88.9%	5.8%
C3	90	45	50.0%	10.3%
C4	255	147	57.6%	5.3%
C5	663	272	41.0%	4.6%
C6	130	41	31.5%	12.7%
C7	172	130	75.6%	4.2%
C8	96	80	83.3%	4.5%
C9	88	46	52.3%	10.0%
TOTAL	**1,602**	**835**		

Table 4 ANOVA results for the 15 management dimensions

Management dimension	Degrees of freedom	Sum of squares	Mean square	F value	p(>F)
Health and safety					
Factor	10	0.4102	0.04102	19.95	<2e-16
Residuals	88	0.1809	0.00206		
Leadership					
Factor	5	0.18359	0.03672	24.42	3.87e-12
Residuals	48	0.07218	0.00150		
Quality					
Factor	13	0.6711	0.05163	6.84	1.53e-09
Residuals	112	0.8453	0.00755		
Risk					
Factor	7	0.2601	0.03716	19.12	1.6e-13
Residuals	64	0.1244	0.00194		
Cost and Schedule					
Factor	7	0.23448	0.03350	28.71	<2e-16
Residuals	64	0.07467	0.00117		
Organization and change					
Factor	8	0.2499	0.031238	16.76	9.56e-14
Residuals	72	0.1342	0.001864		
Technology					
Factor	1	0.004163	0.004163	7.338	0.0155
Residuals	16	0.009077	0.000567		
Innovation					
Factor	14	0.3913	0.027948	11.06	8.04e-16
Residuals	120	0.3033	0.002527		
Communication					
Factor	6	0.13999	0.02333	20.11	2.25e-12
Residuals	56	0.06498	0.00116		
Suppliers					
Factor	8	0.2525	0.031560	10.32	1.69e-09
Residuals	72	0.2201	0.003057		
Corporative goals					
Factor	4	0.01452	0.003631	1.918	0.126
Residuals	40	0.07573	0.001893		
Planning					
Factor	6	0.1489	0.024821	18.68	8.61e-12
Residuals	56	0.0744	0.001329		
Production					
Factor	7	0.06016	0.008594	5.837	2.92e-05
Residuals	64	0.09422	0.001472		
Relation with owner					
Factor	4	0.08981	0.022453	19.85	4.53e-09
Residuals	40	0.04524	0.001131		
Human resource and learning					
Factor	18	0.6160	0.03422	11.25	<2e-16
Residuals	152	0.4622	0.00304		

Table 5. Significantly different management practices among construction companies

DIMENSION	MANAGEMENT PRACTICE
Health and safety	P5: Safety indexes are used to select subcontractors.
	P7: The company uses innovative practices for prevention of accidents.
Leadership	P4: The company applies selection, development and incentive processes to promote leadership.
	P6: The company has strong, collaborative leadership practices throughout its organization to address the challenges it faces.
Quality	P14: The outstanding performance of staff in quality issues is recognized through incentives.
Risk	P4: Risk analysis incorporates uncertainty in a quantitative way (probability theory, for example), to evaluate the potential impact of such uncertainties.
	P5: Apply sophisticated risk analysis methods such as influence diagrams and Monte Carlo simulation, for example.
	P7: There are established policies, procedures and goals for risk management in my company.
Cost and Schedule	P6: Tools are used to identify the causes of results in schedule and costs (5 Why, Value Stream Mapping, Ishikawa Diagram, Pareto Diagrams, etc.)
Organizational Change	P2: During the process of change in the organization information about progress is disseminated.
	P6: Incentives are applied to implement and promote organizational changes.
Technology	P1: The main motivation of your company to acquire new technologies is to achieve a competitive advantage
	P2: The company acquires technology that meet the individual needs, integrating the flexibility to adapt to the changing needs of the users / customers
Innovation	P12: The company provides incentives for those who bring ideas of improvements to processes, products or marketing.
Communication and Information	P4: Communications within the company are made through formally established channels (memos, meetings, email, twitter)
	P6: Virtual collaborative means (BIM) is used to communicate and share information (within the company / with the projects / with the clients / with suppliers).
Supply	P3: In the company other factors besides the price are important in the decision to award a contract of purchase (materials and equipment).
	P6: The company uses inventory control techniques (“sawtooth”, bar codes, etc.) to update procurement planning.
Planning and Programming	P2: The organization conducts periodic planning to determine medium-term objectives.
	P5: Management tools are used for the continuous improvement of planning in the organization (Examples of Management Tools: Fishbone Thorn Diagram, Spaghetti Diagrams, etc.)
Production	P2: In the company, efforts are made to reduce the inventories necessary to fulfill a task, by ordering small lots.
Relationship with Owner	P2: The forms of selection of contractors that are currently used promote a good relationship between the client and my company.
	P5: New types of contract have been proposed and / or implemented to establish the relationship with the principal.
Human Resources	P3: The objectives and policies of the company are always informed to new personnel entering the company.
	P10: Lessons learned workshops are held regularly by areas of interest.

Table 6. Median values of the KPIs from each company's group of projects

KPI median	C1	C2	C3	C4	C5	C6	C7	C8	C9
Cost deviation	0.000008	-0.047700	-0.011600	0.120000	0.158704	-0.016150	-0.064000	0.464700	0.015000
Schedule deviation	0.035750	-0.090900	0.107600	0.169000	-0.211500	0.026610	-0.062300	-0.291500	0.276400
Accident frequency	8.615000	5.140000	5.000000	0.000000	0.000000	0.000000	0.000000	N/D	0.000000
Accident severity	98.810000	74.000000	302.100000	162.800000	0.000000	0.000000	0.000000	N/D	76.340000
Planning effectiveness	0.770500	0.710000	0.810000	0.620000	0.530000	0.667950	0.783800	0.664000	0.909700
Constraint release	0.600000	0.780000	N/D	0.960000	0.363000	0.729100	0.789100	0.652000	0.214700
Quality	27.060000	75.723000	733.200000	22824.300000	N/D	31.740000	0.000000	N/D	N/D
Productivity	0.670000	1.414910	1.342323	1.013000	1.241350	1.117424	1.002640	1.258700	N/D
Contract bid change	1.000000	1.044000	0.985000	1.035000	1.000000	1.175000	1.010000	1.018000	1.040000

Note: N/D = No data were reported by the company.

Table 7. Average rank median KPI by company

Code	Cost deviation	Schedule deviation	Frequency Index	Gravity Index	Planning Effectiveness	Constrain Release	Quality	Productivity	Contract Bid Change
C1	5	6	1	3	6	3	5	8	7.5
C2	8	3	2	5	5	6	3	1	2
C3	6	7	3	1	8	N/D	2	2	9
C4	3	8	6	2	2	8	1	6	4
C5	2	2	6	7	1	2	N/D	4	7.5
C6	7	5	6	7	4	5	4	5	1
C7	9	4	6	7	7	7	6	7	6
C8	1	1	N/D	N/D	3	4	N/D	3	5
C9	4	9	6	4	9	1	N/D	N/D	3

Note: N/D = No data were reported by the company

Table 8. Spearman correlation among management practices and projects' KPIs

MANAGEMENT PRACTICES	KPI	Spearman r	p-value
Relationship with Owner (P5): New types of contract have been proposed and / or implemented to establish the relationship with the principal.	Constraint Release	-0.914	0.002
Cost and Schedule (P6): Tools are used to identify the causes of results in schedule and costs (5 Why, Value Stream Mapping, Ishikawa Diagram, Pareto Diagrams, etc.)	Cost Deviation	0.732	0.025
Human Resources (P3): The objectives and policies of the company are always informed to new personnel entering the company.	Cost Deviation	0.679	0.044
Production (P2): In the company, efforts are made to reduce the inventories necessary to fulfill a task, by ordering small lots.	Accident Severity	0.725	0.042
Risk (P7): There are established policies, procedures and goals for risk management in my company.	Accident Severity	-0.806	0.016
Relationship with Owner (P2): The forms of selection of contractors that are currently used promote a good relationship between the client and my company.	Planning Effectiveness	0.789	0.012
Risk (P5): Apply sophisticated risk analysis methods such as influence diagrams and Monte Carlo simulation, for example.	Planning Effectiveness	0.766	0.016
Organizational Change (P2): During the process of change in the organization information about progress is disseminated.	Quality	0.928	0.008
Communication and Information (P6): Virtual collaborative means (BIM) is used to communicate and share information (within the company / with the projects / with the clients / with suppliers).	Quality	0.899	0.015
Cost and Schedule (P6): Tools are used to identify the causes of results in schedule and costs (5 Why, Value Stream Mapping, Ishikawa Diagram, Pareto Diagrams, etc.)	Quality	0.971	0.001
Production (P2): In the company, efforts are made to reduce the inventories necessary to fulfill a task, by ordering small lots.	Quality	0.886	0.019