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Critical success factors for Six Sigma projects☆

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Abstract

The goal of this article is to identify and understand the relationship between critical success factors for Six Sigma programs and its projects performance, considering Six Sigma projects. This article explores those relationships through PLS (Partial Least Squares) method, using a sample of 149 respondents in Brazil and Argentina. The variables were collected initially by a survey conducted with Black Belts, Green Belts, program managers and company executives and goes further on projects documental analysis. The results show that not all the claimed critical success factors are relevant for program or project performance, what could direct the effort of companies into working harder in the relevant ones. This study has a noteworthy contribution to Six Sigma literature presenting a structural model that shows the significant impact of Six Sigma Method, Project Management and the Project Manager competencies on project performance.

Keywords: Project management; Six sigma; Project manager; Project success; Competence

1. Introduction

Many companies have sought to adopt the Six Sigma program, as a way to improve their results. This search is motivated by the results obtained by companies such as Motorola, AlliedSignal, 3M, and GE, who were the pioneers in the adoption of the program (Pande et al., 2000; Snee and Hoerl, 2003). Despite these organizations reporting hundreds of millions of dollars as a result of the adoption of Six Sigma since the 90s (Pande et al., 2000; Seri, 2002), definitions of the scholarly literature on what is Six Sigma are much more recent and the empirical evidence of the impact on results are restricted to few studies.

Despite the success claimed by practitioners with the adoption of Six Sigma, in academia, the first discussions on the subject were related to the discussion on the Six Sigma which can be regarded as a new form of different quality management TQM (Kaynack, 2003; Kwak and Anbari, 2006; Schroeder et al., 2008; Yeung et al., 2006; Zu et al., 2008).

Although Kaynack (2003) argue that the Six Sigma can be considered "TQM on steroids", Schroeder et al. (2008) and Zu et al. (2008) indicate that the Six Sigma uses a common platform of knowledge, practices, and quality resources, complementing them with some features and specific resources in order to increase its effectiveness.

Evaluating the recurring themes in research on Six Sigma, plus getting a coherent definition and presentation of cases of application of the program in various industries, a recurring theme that arises frequently in the research is the analysis of critical success factors of Six Sigma programs, as shown by Marzagão et al. (2014). The interest in the discussion of this issue has grown in the number of citations, although still incipient in the number of published articles.

Considering studies on the topic, Goh (2010) reviews the practices over the 25 years of implementation of Six Sigma, suggesting opportunities for improvement in the aspects of evolution of the structured method of troubleshooting, issues related to the conflict between applications of sophisticated

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techniques and practical outcomes perceived, which suggests that a critical success factor quite cited in literature, which is the application of statistical and quality tools (Antony and Bañuelas, 2002; Antony and Desai, 2009; Bhote, 2002; Brady and Allen, 2006; Brun, 2011; Dedeke, 2002; Firka, 2010; Hahn, 2005; Henderson and Evans, 2000; Keller, 2001; Kim, 2010; Kumar and Antony, 2008; Kumar et al., 2009; Martens, 2001; Pande et al., 2000; Pfeifer et al., 2004; Pyzdek, 2003; Smith et al., 2002; Snee and Hoerl, 2003; Timans et al., 2011) should be viewed with caution because a full application of all the tools could not always predict the success of the program. The relation between Six Sigma and project has been explored in Project Management literature, aligned with the theoretical proposition that the successes of operational excellence concepts, such as Six Sigma, "leads to project excellence" (Basu, 2014, p. 180), and the idea that successful implementation of major managerial innovations as six sigma are "critical to the survival of organizations, while relying on project management and change management" (Hornstein, 2015, p. 294). Moreover, Nair et al. (2011) study the relationship between the Six Sigma project context, its elements and the success of the initiative, suggesting deeper study from the link between the themes of project, its complexity and context and the performance of such projects, suggesting that project performance can be affected not only by directly Six Sigma program variables but also the way Six Sigma program is inserted in company, which refers to the need to assess the outcome of the program and projects moderated by those aspects. Parast (2011) also proposes eight propositions relating the effect of Six Sigma projects on innovation and firm performance. Both Shafer and Moeller (2012) and Swink and Jacobs (2012) demonstrate quantitatively the effect of the Six Sigma program in the performance of companies that adopted Six Sigma, finding significant positive effects. Both studies suggest investigating in future research how aspects of form and intensity of adoption of Six Sigma practices correlate with benefits earned by companies adopting Six Sigma.

In addition, to these studies, the validation of critical success factors in each country has been a recurring theme. The works of Sharma and Chetiya (2010) and Desai et al. (2012) discuss and validate critical success factors in enterprises in India, Brun (2011) discusses the critical success factors in Italy and Zailani and Sasthriyar (2011) also discuss those critical success factors in Malaysia.

In this context, this study aims to contribute to fulfilling the discussed research gap by proposing and validating a research model on critical success factors (CSFs) for Six Sigma programs. Moreover, it aims to relate those CSFs and project success. The methodological approach is a survey-based research, using structural equation modeling to validate the research model.

This paper is structured in 6 sections. In the next section, we provide a theoretical overview that addresses the literature on six sigma and project success. The methodological approach of the research is detailed in Section 3, followed by the results in Section 4. Section 5 presents the discussion and our conclusions are in Section 6.

2. Literature review

Analyzing in more detail these references, it is possible to identify common elements in these definitions, but with different settings for each key element that makes up the Six Sigma.

In the literature of the practitioners, the definitions of Six Sigma are wider. To Pande et al. (2000, p. 3), Six Sigma can be defined as "a flexible system for improved performance and leadership". To Rotondaro (2002, p. 18), "Six Sigma is a working philosophy to achieve, maximize and maintain the commercial success, through the understanding of customer needs". For Harry and Schroeder (2000), Six Sigma is a strategy that relies on its ability to fulfill its goals. Harry and Schroeder (2000) also mention that the Six Sigma is a strategic initiative and can be considered by itself as a vehicle for other strategic initiatives.

For Linderman et al. (2006), Six Sigma is an organized and systematic method for improvement of processes and the development of new products and services, based on statistics and scientific techniques, with the purpose of reducing defects defined by customers. On Linderman et al. (2006, p. 780), the authors emphasize that "nothing is radically new in Six Sigma but Six Sigma does place a strong emphasis on challenging specific goals".

Schroeder et al. (2008, p. 540) define Six Sigma as "parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives." They also suggest that Six Sigma is seen as a process of organizational change.

Zu et al. (2008, p. 633) divides his definition of Six Sigma roles and structure practices between keys. According to the authors, "Six Sigma role structure is considered as an infrastructure practice in that it is part of human resource infrastructure to assist the deployment of Six Sigma". Core practices already are described as "Six Sigma structured improvement procedure and Six Sigma focus on metrics", which emphasizes "the use of scientific methods, statistics, and quantitative metrics tools".

Krueger et al. (2014) concluded, in its research based on grounded theory, that the Six Sigma program has a number of key aspects, and that success cannot be achieved focusing on only a few of them. In their study, they found differences between critical aspects correctly addressed companies studied, such as leadership, which may be related to the formation of parallel-meso structure and the roles to be played by the direction of the company, training, which is related to the technical qualifications of "Belts", affecting the knowledge of Six Sigma of members of parallel-meso structure and rigor in execution, which is linked to the application of structured method DMAIC and its tools. In this study, however, there were still unresolved points found in the practical approach as to project selection and alignment with other initiatives of the company, suggesting that these aspects should be studied in greater depth, which shows that there is, even among practitioners, a gap related to the corporate understanding of the benefits to be obtained from the projects, in which the Six

Sigma projects can bring a different contribution from other existing programs within the company and the competition possible for resources, with more than one program related to process improvement and quality increase.

While for Zu et al. (2008), the roles in Six Sigma is directly linked with the existence and importance of Green Belts and Black Belts, Schroeder et al. (2008) describe the need for these figures as " improvement specialists", but proposes a broader definition for the logic of roles in Six Sigma, including the performance of the company's leadership as support and strategic alignment by creating a system of roles that allow real autonomy in changes of process, in which the authors define as " parallel-meso structure".

Schroeder et al. (2008), in the definition of parallel-meso structure, in addition to the hierarchy system parallel to the organogram of the organization, emphasizes two key roles of this set of people, declared as strategic selection of projects and engagement of leadership. On strategic selection of projects, Schroeder et al. (2008) mention the importance of the projects which are chosen for leadership, thus ensuring high commitment of the leaders and thus avoiding projects that do not generate significant impacts to the organization. Already for Zu et al. (2008), part of project selection activity is defined as a structured procedure for improvement, since it considers that the selection of projects must go through a planned and controlled process, and another part of this activity can be defined by the practice of Six Sigma focus on metrics, including the need to ensure that the goals of the projects should significantly affect the result of the business unit.

For Zu et al. (2008), in addition to the structured procedures for planning and selection of projects, the practice of structured Six Sigma procedures also encompasses the adoption of meta-DMAIC routine for the conduct of the projects, which is consistent with the definition of Schroeder et al. (2008) for the structured method. But in addition, the definition of Zu et al. (2008) encompasses all the procedures for monitoring the progress of projects, progress records and managing the activities of quality, which Schroeder et al. (2008) included in the definition of engagement of leadership.

Some authors suggest assessing the strategic benefit of the program, whereas including how these aspects affect the selection of projects and resource (Goh, 2010), as it is understood, for this article, that the formation of the portfolio of Six Sigma projects and the resources that will be allocated to it should be clearly linked to the strategic benefit which the organization intends to obtain from the program, featuring, in some way, the need to treat the Six Sigma program within companies as a project portfolio.

Comparing the note that variables defined by Schroeder et al. (2008) as strategic project selection and engagement of leadership with the variables proposed by, and that for Zu et al. (2008) as part of the practice of structured Six Sigma procedures, see common elements between them. Given the characterization of the Six Sigma program as an initiative led by projects, we can compare both settings with those proposed by, PMI (2013) that can be addressed also as project portfolio management, which defines portfolio as a collection of projects, programs and other activities grouped into a set in order to facilitate the management activities which aim to achieve the strategic objectives and the management of the portfolio, and Archer and Ghasemzadeh (1999), which also discuss the management of the portfolio, highlight that the activities of portfolio management projects cover strategic evaluation of the projects, the creation of methods that allow stakeholders use the prioritization tools with which they feel most comfortable but allowing the analysis of relevant data and decision-making and also the periodic assessment of the portfolio, contemplating the impact of eventual changes in the premises projects initials of selection, as well as enabling the adaptation to changes in the environment portfolio of the company (Padhy and Sahu, 2011).

The impact of soft side of project management on project success has been explored recently in the PM literature (Carvalho and Rabechini, 2015). Gutiérrez et al. (2012) explore the relationship between learning organization orientation, absorption capacity and factors such as teamwork and management aspects project development, and suggests that the Six Sigma should be studied under the aspect of cultural change, and the effect of the knowledge generated in the development of new products and processes. This work highlights the key role of project leaders, their knowledge, and skills, as influencers in project performance, suggesting that this factor should be considered as a key element in the success of projects. Project team should have problem solving competence, such those that Six Sigma provides, allowing identifying, analyze, and solve problems (Lin et al., 2015) and learning processes that can influence project performances (Todorović et al., 2015).

These definitions of project portfolio management are aligned with the strategic selection constructs projects and engagement of the leadership of Schroeder et al. (2008) and also the practice of structured Six Sigma procedures proposed by Zu et al. (2008). This consistency allows you to treat these factors characterizing the keys Six Sigma as portfolio management practices projects and is also consistent with the factors characterizing the keys Six Sigma described earlier.

With this, one can also notice that the definition of Zu et al. (2008) for structured procedures covers both items related to the management of each project individually (meta-DMAIC routine) regarding the management of portfolio, while Schroeder et al. (2008) allocate the portfolio management activities within the role of parallel-meso structure by separating the management activities of each project individually, which is treated as structured method.

In the definition of Schroeder et al. (2008) of structured method, in addition to the use of meta-DMAIC routine, approached by Zu et al. (2008) within the practice of structured improvement procedures, also emphasizes the type of tools used within the meta-routines, specifying that in addition to the seven basic tools of quality, there are a number of more advanced tools which also characterize the structured method. Linderman et al. (2006) corroborate this more comprehensive approach to the structured method in relation to the performance of the program.

Schroeder et al. (2008) also explore, in its definition of Six Sigma, the need for application of metrics for the projects developed by dividing them into financial metrics and customer-oriented metrics, claiming that in general TQM initiatives working with General indicators for processes, but not with specific indicators for each project. Already Zu et al. (2008), in practice set to Six Sigma focus on metrics, covers more than the mere existence of financial performance indicators and quality (which it treats in the practice of "quality information", which is not part of the core of the Six Sigma), treating as a key element of the program Six Sigma concern with targets for such indicators in an approach more aligned with Linderman et al. (2006), which emphasize the importance of the projects have clear targets for the organization, and that these are challenging but feasible. Table 1 shows the definitions of Six Sigma.

Comparing these settings, this paper proposes Six Sigma definition as the Six Sigma program can be defined as the implementation of a managed portfolio of process improvement projects, which uses a defined method to conduct projects by a specified Project Management routine, using project leaders with special project leader competencies.

This definition is based on comparative framework supports the definitions analyzed. From this definition of Six Sigma, this article proposes relationships of variables that affect the success of the projects. Considering the elements of the proposed definition, we can understand what type of effect variables proposals may have on the Six Sigma Projects.

The Six Sigma Method could be applied with distinct intensity and might be seen as variable, as defended by Shafer and Moeller (2012) and Swink and Jacobs (2012). The degree of application of Six Sigma Method might be different from project to project, given that the fact of the company call it Six Sigma projects, does not guarantee that the sequence of steps from troubleshooting algorithm is being applied correctly. Moreover, some authors advocate the use of every technical tools and statistics on all projects (Antony and Bañuelas, 2002; Bhote, 2002; Brady and Allen, 2006; Brun, 2011; Dedeke, 2002; Firka, 2010; Hahn, 2005; Henderson and Evans, 2000; Keller, 2001; Kim, 2010; Kumar and Antony, 2008; Kumar et al., 2009; Martens, 2001; Pande et al., 2000; Pfeifer et al., 2004; Pyzdek, 2003; Smith et al., 2002; Snee and Hoerl, 2003; Timans et al., 2011), while others argue for the use of the simplest tools (Brady and Allen, 2006; Clegg et al., 2010) which may be related to the success of each project individually.

However, the project result can also be affected by technical and behavioral skills of project leaders, defined in this paper as Six Sigma project manager competencies. Already the characteristics of project experts tend to affect every project individually since its role is to lead the portfolio projects, but can also affect the performance of the portfolio as a whole since they are part of the management structure of the portfolio of projects.

Assuming the elements of this definition, we start now to identify which is, in the literature, the characterization of each of these elements and their relationship with the projects ' success, in order that we can identify which of these features can actually be considered critical to the success of the Six Sigma program and its projects.

2.1. Six Sigma and project performance

Many authors of Project Management literature associate project performance with measures of cost, time and quality, also known as "iron triangle" (Atkison, 1999; Berssaneti and Carvalho, 2015). Even being the most cited criteria; these are not consensus in the literature. There are authors like De Wit (1988), who argue that the best measure of project success is in meeting its objectives, or Carvalho et al. (2015) that include

Table 1
Six Sigma definitions framework.

<table>
<tr><th>Schroeder et al. (2008)</th><th>Zu, Fredendall and Douglas (2008)</th><th>Linderman et al.</th><th>Author's proposition</th><th>Components</th></tr>
<tr><td rowspan="3">Structured method</td><td></td><td rowspan="2">Six Sigma tools and adherence to methods</td><td rowspan="2">Six Sigma method</td><td>Use of the 7 basic quality tools, plus advanced tools</td></tr>
<tr><td rowspan="2">Structured Six Sigma procedure
Six Sigma focus on metrics</td><td>DMAIC routine goal for conducting projects</td></tr>
<tr><td></td><td rowspan="5">Six Sigma project management</td><td>Periodic monitoring of leadership on the progress of the portfolio of projects</td></tr>
<tr><td>Performance metrics</td><td></td><td>Clear and challenging goals</td><td>Selection of projects that affect them financially or strategically, business unit with setting targets</td></tr>
<tr><td rowspan="3">Meso-parallel structure</td><td rowspan="3">Structure of roles of Six Sigma</td><td rowspan="3"></td><td>Monitoring the progress of the project with use of financial metrics</td></tr>
<tr><td>Monitoring the progress of the project with the use of object-oriented metrics customers.</td></tr>
<tr><td>Existence of black belts and green belts</td></tr>
<tr><td></td><td></td><td></td><td>Six Sigma project manager competences</td><td>Interpersonal abilities of Six Sigma project leaders, such as black belts and green belts</td></tr>
</table>

margin variations. Shenhar and Dvir (2007) understand that the projects are part of the strategic management of an enterprise, and, therefore, its success must be linked to its contribution to the business, in short- and long-term through five categories: efficiency; impact to the customer; impact on the team; business and direct success; and preparation for the future. Carvalho et al. (2015) include another category sustainability (environment and social) once the five other categories contemplate the economic dimension of sustainability.

Applying these definitions in the context of Six Sigma projects, it is expected that such projects may lead to improved operational performance, providing return on invested capital faster, with lower production costs, more efficiency in spending on research and development, development of new products with greater speed and meeting the expectations of its customers (Harry, 1998).

Several authors mention financial metrics (Carvalho, 2002; Harry and Schroeder, 2000; Pande et al., 2001) or customer satisfaction (Bertels and Patterson, 2003; Carvalho, 2002; Goh and Xie, 2004; Pande et al., 2001) as objectives to be pursued by the Six Sigma projects. Linderman et al. (2003) emphasize the presence of metrics and goals as a distinctive feature of Six Sigma, the measurement of the achievement of such goals as a key item for the results of the projects. With this, it is understood that the metrics of success of Six Sigma projects are linked to the demonstration of improvements in indicators of the process, that affect the organization or financial improvement of customer's satisfaction.

Ray et al. (2004) propose the definition of a successful Six Sigma project in a most comprehensive way, as a set of achievement of these objectives proposed in metrics, but also the involvement of leadership, the fulfillment of the schedule, the depth of analysis, the change in the process and the presence of reviews and monitoring of the project. From the items cited by Ray et al. (2004), aligning them with the discussion of success of projects proposed in Project Management literature, we can understand that Six Sigma project success could be defined by achieving goals related to customer satisfaction and Financial Returns, as well as the deadlines and effective changes in processes, along with the description of Shenhar and Dvir (2007).

Leadership involvement and the presence of reviews and monitoring of the project seem more like critical success factors driving the project than definitions of the success of a Six Sigma project, and that's the reason why, within this work, they will be treated as independent variables instead of dependent ones.

2.2. Six Sigma Project Management

Some authors warn for the need of applying concepts of Project Management as a critical factor for the success of these projects (Antony, 2006; Antony et al., 2007a, 2007b; Antony and Bañuelas, 2002; Antony and Desai, 2009; Brady and Allen, 2006; Brun, 2011; Coronado and Antony, 2002; Kumar and Antony, 2008; Kumar et al., 2009; Petzel, 2006; Pfeifer et al., 2004; Timans et al., 2011; Topfer, 2007). A Project Management item described by the authors is the concern about the balance between project scope and deadlines. In general, the Six Sigma projects have short duration, around six months, so the scope of the project, according to these authors, should be carefully defined to ensure that these projects in fact can meet this deadline because it understands that this is the ideal time for the realization of this type of project (Goh, 2002; Pfeifer et al., 2004).

An important issue in the Six Sigma Project Management is to establish the parallel-meso structure, analyzing the presence of all the roles described in the literature.

The importance of the people involved in meso-structure parallel to the performance of the Six Sigma program is the need for human resources allocated for the conduct of projects (Pyzdek, 2003; Snee, 2001).

In this human resources investment, some authors list as required an adaptation of roles and functions (Antony et al., 2007a, 2007b; Coronado and Antony, 2002; Minarro-Viseras et al., 2005; Topfer, 2007), with the creation of the roles of "Belts", which are continuous improvement experts that will conduct the projects (Cho et al., 2011; Harry, 2000).

It is recommended that this structure is multifunctional (Brady and Allen, 2006; Kumar and Antony, 2009), project leaders to respond, while driving the project, executives responsible for the areas where the project is being developed, having this Executive a "Champion" or "Sponsor" of this project, and this report is temporary (Kim, 2010; Nonthaleerak and Hendry, 2008).

In addition to the roles of "Belts" and "Champions", also appoints members of meso-structure that will act as mentors and multipliers, such as Master Black Belts and Black Belts (Antony and Bañuelas, 2002; Brue, 2002; Harry and Schroeder, 2000; Henderson and Evans, 2000; Keller, 2001; Snee and Hoerl, 2003).

In addition to the training of mentors, several authors also mention the need for other roles with training in Six Sigma for the projects and other teams involved (Chakrabarty and Chuan, 2009; Harry, 2000; Henderson and Evans, 2000; Hilton and Sohal, 2012; Johnson and Swisher, 2003; Kumar and Antony, 2009; Minarro-Viseras et al., 2005). Many companies call this basic level of training with names like White Belts or Yellow Belts. This formation, unlike Black Belts or Green Belts, has a menu of more flexible curriculum and a more informative character, with the goal of facilitating the conduct of projects by means of communication on various levels of the company.

Given that one of the difficulties with the experts in improvement mentioned in literature refers to lack of resources, both the number of people allocated as Green Belts and Black Belts, such as the amount of time devoted to these activities (part-time x total time) and also the amount of people dedicated to these activities, affect the availability of expert resources for improvements to the conduct of projects. With regard to "Belts", there is some controversy in its operations. While some authors advocate the use of Black Belts as full-time project leaders (Byrne and Norris, 2003; Nonthaleerak and Hendry, 2008; Pande et al., 2000), other authors propose that there is a part of project leaders working in part-time, since the portion of time be standardized and allow the appropriate balance between routine activities and the conduct of the project (Goldstein, 2001; Kim, 2010; Kumar and Antony, 2009), because, without sufficient resources, the performance of a Six Sigma project will be affected.

Hypothesis 1. Six Sigma project performance is improved when Six Sigma Project Management is completely fulfilled.

2.3. Six Sigma method

The use of a structured method, considered as a distinctive factor of Six Sigma, can be characterized by the use of meta-DMAIC routine, along with the use of appropriate tools for the conduct of Six Sigma projects (Linderman et al., 2006; Schroeder et al., 2008; Zu et al., 2008).

According to Linderman and Chandrasekaran (2010), the DMAIC method (Define, Measure, Analyze, Improve, Control) can be characterized as a meta-routine, that is, a routine that allows you to change existing processes or routines (Ghosh and Sobek, 2002). Despite criticisms like De Mast and Lokkerbol (2012) regarding meta-DMAIC routine be the not applicable in all cases, the DMAIC is, within the Six Sigma, the meta-applied routine in most projects.

The goal is to eliminate the source of the problem and not its symptoms, providing permanent results (Clegg et al., 2010). According to several authors, the understanding and disciplined application of this meta-routine is a critical success factor for the Six Sigma projects (Antony et al., 2007a, 2007b; Antony and Bañuelas, 2002; Brady and Allen, 2006; Coronado and Antony, 2002; Dedeke, 2002; Goh, 2002; Henderson and Evans, 2000; Martens, 2001; Pfeifer et al., 2004; Smith et al., 2002; Snee and Hoerl, 2003).

Since the objective of the meta-routine is to provide a structured method for troubleshooting, non-adoption or incorrect adoption of this algorithm could make the project really don't address the root causes of the problem to be solved by the project.

Over meta-routine, there are a number of tools whose use is associated with Six Sigma. Some authors cite as common tools in Six Sigma using process mapping, root cause analysis, brainstorming, control charts, Pareto charts, benchmarking, variance analysis, FMEA, hypothesis tests, scatter diagrams, the design of experiments (Antony et al., 2007a, 2007b; Carvalho et al., 2007). The use of these tools allows you to deepen the knowledge of those involved about the nature of the problems, using a knowledge base for the formulation of more concrete actions for improvement. Some authors consider that the domain and application of Six Sigma tools in the projects are fundamental to its success (Antony and Bañuelas, 2002; Antony and Desai, 2009; Bhote, 2002; Brady and Allen, 2006; Brun, 2011; Dedeke, 2002; Firka, 2010; Hahn, 2005; Henderson and Evans, 2000; Keller, 2001; Kim, 2010; Kumar and Antony, 2008; Kumar et al., 2009; Pande et al., 2000; Pfeifer et al., 2004; Pyzdek, 2003; Smith et al., 2002; Snee and Hoerl, 2003; Timans et al., 2011). However, some authors emphasize that the application of the tools must be adaptable and that most problems can be resolved without the use of sophisticated tools (Brady and Allen, 2006; Clegg et al., 2010), while others emphasize that there are types of operational research tools or mathematical modeling that could be used (De Mast and Lokkerbol, 2012) and that more important than the tools itself, is the understanding of the impacts of changes in business processes and its effect on strategy (Goh, 2010).

Hypothesis 2. Six Sigma project performance is improved when Six Sigma method is completely adopted.

2.4. Six Sigma project manager competencies

Several authors show the importance of careful selection of the Belts based on their skills as leaders (Hilton and Sohal, 2012; Johnson and Swisher, 2003; Kumar and Antony, 2009; Zu et al., 2008). However, the exact characteristics needed for a successful Six Sigma project leader have not been described in this universe. Gijo and Rao (2005), to identify the obstacles in the implementation of Six Sigma in enterprises, mention the difficulty of execution of projects due to lack of resources and the difficulties of selecting people with interpersonal skills to lead projects. Other studies also emphasize the need to find project leaders with managerial skills for conducting the project (Gijo and Rao, 2005; Johnson and Swisher, 2003) that could be aligned with project manager competencies in PM literature (Takey and Carvalho, 2015). This need for "Belts" have management skills, in addition to the technical skills, cause the number of resources able to conduct projects is even lower, compounding the issue of lack of resources for conducting projects. In addition, the performance of each project conducted can be affected by the capacity of the "Belt" in dealing with management issues, as stated by Gutiérrez et al. (2012).

In addition, behavioral skills are required of the experts in improving a range of technical skills (Hilton and Sohal, 2012). Such skills are provided to "Belts" through training aimed at empowering project leaders so that they have the domain of Six Sigma Method, as well as the tools to be used in the improvement initiatives.

In addition to the training, some authors still point out the need for guidance and support conducted by Master Black Belts, being that these may be the company's own employees or even specialized consultancies contracted (Goldstein, 2001; Kim, 2010). This statement is based on the realization that in addition to the trainings, configured as "learning by seeing", an important part of the acquisition of technical knowledge takes place during the execution of the projects, where the adaptation of previous experiences is part of a generation of learning (Arumugan et al., 2013; Choo et al., 2007; Gutiérrez et al., 2012).

The goal of this whole training structure is to ensure the project leader and his team the technical knowledge required for the application of the structured method. Therefore, if these knowledge transfer activities are not successfully developed, the ability of the "Belts" to apply the Six Sigma Method will be impaired, slowing down project results in which they participate. The ability of Six Sigma project leaders to play their roles in the meso-structure will also be impaired if the knowledge transfer is unsuccessful, and the Six Sigma Project Management in this condition could not be completely fulfilled.

Hypothesis 3. Six Sigma project performance is improved when the Six Sigma project manager has behavioral competencies of a project leader.

Hypothesis 4. Six Sigma Project Management is improved when the Six Sigma project manager has behavioral competencies of a project leader.

Hypothesis 5. Six Sigma project method is improved when the Six Sigma project manager has behavioral competencies of a project leader.

2.5. Model development

Based on the understanding that the Six Sigma program can be defined as the implementation of a managed portfolio of process improvement projects, which uses a defined method to conduct projects by a specified Project Management routine, using project leaders with special project leader competencies, its success depends on the form of deployment of Six Sigma within enterprises to this understanding. However, each of the elements described in the definition cannot be defined as existing or non-existing, as a binomial variable. Instead, we propose to measure a greater or lesser adherence to each of them, which leads to the need to characterize the presence of each construct assessing each of the elements described in the characterization of the constructs.

From the above reasoning, it is possible to identify that the references corroborate the hypothesis that elements described are in fact elements that contribute to the success of Six Sigma projects, as shown in Table 2.

Given the theoretical framework presented, it is possible, in addition to identifying the critical success factors described in

Table 2
Six Sigma critical success factors listed in literature.

Author's proposition of Six Sigma key elements	Critical success factors in literature related to this characteristic	Reference
Six Sigma Project Management	Clear roles in the Six Sigma structure	Antony et al. (2007a, 2007b), Brady and Allen (2006), Coronado and Antony (2002), Kim (2010), Kumar and Antony (2009), Minarro-Viseras et al. (2005), Nonthaleerak and Hendry (2008), Pyzdek (2003) and Topfer (2007)
	Full time dedicated Black Belts	Byrne and Norris (2003), Nonthaleerak and Hendry (2008) and Pande et al. (2000)
	Clearly allocated Green Belts	Goldstein (2001), Kim (2010) and Kumar and Antony (2009)
	IT or Knowledge management structure	Dedeke (2002), Goldstein (2001), Henderson and Evans (2000), Kumar and Antony (2008), Kumar et al. (2009) and Pande et al. (2000)
	Strategic project selection	Antony and Bañuelas (2002), Antony and Desai (2009), Brun (2011), Byrne and Norris (2003), Dedeke (2002), Hilton and Sohal (2012), Johnson and Swisher (2003), Kumar and Antony (2008, 2009), Kumar et al. (2009) and Timans et al. (2011)
	Long term plus short term benefit project selection	Hilton and Sohal (2012) and Pande et al. (2000)
	Projects selected for important stakeholders	Clegg et al. (2010) and Kim (2010)
	Periodic and constant project review	Antony and Bañuelas (2002), Breyfogle (1999); Dedeke (2002), Goldstein (2001), Harry and Schroeder (2000), Henderson and Evans (2000), Kumar and Antony (2009), Martens (2001), Pande et al. (2000), Pfeifer et al. (2004), Pyzdek (2003) and Snee and Hoerl (2003)
Six Sigma project manager competencies	Behavioral characteristics of Black Belts and Green Belts	Hilton and Sohal (2012), Johnson and Swisher (2003), Kumar and Antony (2009) and Zu et al. (2008)
	Training for Master Black Belts and Black Belts	Antony and Bañuelas (2002), Brue (2002), Harry and Schroeder (2000), Henderson and Evans (2000), Keller (2001) and Snee and Hoerl (2003)
	Massive training in Yellow Belts or White Belts	Chakrabarty and Chuan (2009), Harry (2000), Henderson and Evans (2000), Hilton and Sohal (2012), Johnson and Swisher (2003), Kumar and Antony (2009) and Minarro-Viseras et al. (2005)
	Master Black Belts support provided	Goldstein (2001) and Kim (2010)
Six Sigma method	Adherence of project management with DMAIC steps	Antony et al. (2007a, 2007b), Antony and Bañuelas (2002), Brady and Allen (2006), Coronado and Antony (2002), Dedeke (2002), Goh (2002), Henderson and Evans (2000), Martens (2001), Pfeifer et al. (2004), Smith et al. (2002) and Snee and Hoerl (2003)
	Use of Six Sigma tools	Antony and Bañuelas (2002), Antony and Desai (2009), Bhote (2002), Brady and Allen (2006), Brun (2011), Dedeke (2002), Firka (2010), Hahn (2005), Henderson and Evans (2000), Keller (2001), Kim (2010), Kumar and Antony (2008), Kumar et al. (2009), Martens (2001), Pande et al. (2000), Pfeifer et al. (2004), Pyzdek (2003), Smith et al. (2002), Snee and Hoerl (2003) and Timans et al. (2011)
	Use of project management tools	Antony (2006), Antony et al. (2007a, 2007b), Antony and Bañuelas (2002), Antony and Desai (2009), Brady and Allen (2006), Brun (2011), Coronado and Antony (2002), Kumar and Antony (2008), Kumar et al. (2009), Petzel (2006), Pfeifer et al. (2004), Timans et al. (2011) and Topfer (2007)
	Short projects (6 months)	Goh (2002) and Pfeifer et al. (2004)

the literature, to deploy in the most studied aspects of quantitative and qualitative work on the Project Management that link these critical success factors as independent variables with project and Six Sigma program as dependent variables. It is possible to affirm that the absence or insufficiency of any of these critical success factors, as well as some of its subcomponents, affects in any way the outcome of the projects?

Then, it is possible to propose the following structural model for the understanding of the problem, according to Fig. 1, which represents the simplified model:

3. Research methods

The research applies a quantitative methodological approach structured in two phases. The first phase was, conceptual model proposition, was based on an in-depth literature review, which the overview was presented in the previous section. The second phase was the field research looking for empirical validation through a survey-based research, applying the structural equation modeling (Hair et al., 2014) to validate the research model and check the research hypotheses.

3.1. Data collection

Six Sigma projects conducted in Brazil and Argentina were used as units of analysis in this paper. An on-line survey was applied to 387 Six Sigma practitioners, and 149 responses were obtained from people involved in the conduct of Six Sigma projects between Black Belts, Green Belts, and Six Sigma programs managers of 37 companies (38% response rate). Sampling conducted does not follow probabilistic criterion, because it is impossible to have access to the entire population of projects conducted in this period and region. Therefore, this research was done with a non-probabilistic sample, based on questionnaires distribution "snowball" like, within companies that adopt Six Sigma, as well as in Six Sigma program practice forums and Six Sigma internet forums. While this sampling produces results which cannot be generalized by the nature of the identification of the units of analysis, it's expected that the results could cast light on possible associations between factors, even if in a limited context. After this data collection, the documental phase collected project reports and other data available about the Six Sigma project and Six Sigma program.

The profile of respondents selected was: Black Belts, Green Belts, managers and directors responsible for the results of the Six Sigma program within their organizations.

The research instrument is based on the literature review presented in Section 2, particularly Tables 1 and 2. The scales used in all items of the Survey were obtained through a Likert-type scale from 1 to 7 ranging from 1 (I completely agree) to 7 (strongly disagree). This is an ordinal scale, however, for structural equations treatment, this range is assumed to be continuous.

3.2. Operationalization of the variables

The detailed description of all variables of the research model is presented in Table 3.

The research model (see Fig. 1) has three independent (Xs) latent variables: Six Sigma Method (SSM), Project Management (PM) and Project Manager Competencies (PMerC). All latent variables were designed as first-order deployed in reflective indicators as presented in Table 3.

The dependent (Ys) variables were used to explore the project performance construct, using data of respondent

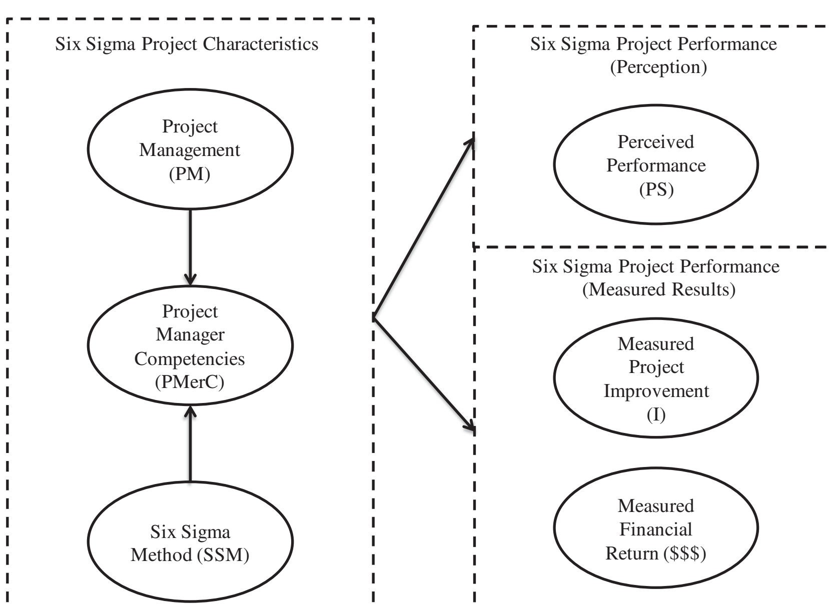

Fig. 1. Simplified model relating Six Sigma critical success factors with project performance.

Table 3
Research variables.

Latent Variable	Indicators	Characteristic
SSM — Six Sigma method	%ferr/SST	% of Six Sigma tools applied
	v25*	The project was developed under the six sigma Method
	v26*	The method used for conducting the project was DMAIC or DMADV (for DFSS projects)
	v27*	All DMAIC steps were completely fulfilled
PMerC — project manager competencies	v28	Change agent
	v29*	Effective communicator
	v30*	Customer defender
	v31*	Team manager
	v32*	Motivated to lead
	v33	Result oriented
	v34	Positive thinking
	v35*	Respect for the others
	v36*	Problem solver
	v37*	Personal efficacy
	v38*	Cognitive abilities
	v39*	Managerial abilities
	v40*	Impact and influence in the organization
	v41	Interpersonal comprehension
PM — project management	v42*	The project was led by a full time Six Sigma leader
	v43*	Project sponsor fully supported project development
	v44	Managers supported and allocated resources for project conduction
	v45	Project leader received complete Six Sigma project education and training
	v48*	There was a project charter containing indicators, goals, deliverables and scope
	v49	There was a time schedule with clear milestones
	v50	There was a budget clearly stated.
PS — project success perception	v84*	This project produced long term benefit
	v85*	This project produced short term benefit
	v86*	The project expectations were meet or exceeded
	v87*	The team had superb results with the project
	v88*	Financial results or strategic impact were significant for this project
PT1 — project type Shenhar	v20*	Novelty
	v21*	Technology
	v22*	Complexity
	v23*	Time Rush
PT2 — project type Six Sigma (DMAIC, DFSS)	v69*	Traditional project
	v70*	Others
$$$ — financial return	v81*	Financial result achieved by the project
I — improvement	v82*	% of process metric improvement achieved by the project

Note: *Indicators that remain in the validated model.

perception and data of measured results of the project extracted from reports. The first independent latent variable is project success perception (PS), which was designed as first-order deployed in reflective indicators (see Table 3). The other two independent variables — financial return ($$$) and improvement (I) are measured with a single indicator; thus, they cannot be interpreted as latent variables but as the indicator itself, as shown in Table 3.

Finally, the research model checks the influence of two control variables related to the project type — PT1 and PT2. The first PT1 is first-order reflective using the diamond model (Shenhar and Dvir, 2007) — complexity, novelty, pace, and technology. Second, the PT2 is related to the Six Sigma project type deployed in traditional DMAIC or others such as Design for Six Sigma (DFSS).

3.3. Data analysis

The data collected using the methods described above have been treated by Structural Equation Model (SEM), with Partial Least Squares estimation (PLS), and use of SmartPLS software.

Structural equation modeling is a multivariate technique that combines aspects of multiple regression (examining dependency relations) and factor analysis (representing concepts measured – factors – with multiple variables) to estimate the number of interrelated dependency relationships simultaneously (Hair et al., 2009).

A distinction is made between two families of techniques of SEM, one based on covariance, represented by the LISREL and the other based on variance, represented by the PLS (Henseler et al., 2009).

The Partial Least Squares (PLS) has been used by a large number of researchers from various disciplines, according to a study conducted by Henseler et al., 2009 (2009). Among the reasons for this acceptance are the lowest requirements in relation to the size of the sample and the data distribution (Zwicker et al., 2008).

To test the dimensionality of the constructs used the Exploratory Factor Analysis (EFA), suitable for the initial stage of development of scale and to gain insight into the potential dimensionality of the items and scales (Netemeyer et al., 2004).

To test the reliability of constructs, it was verified the internal consistency of the items that make up. The coefficient Alpha of Cronbach's alpha's (1951) is the most widely used to test the reliability, however, there is a criticism of the use of Cronbach's alpha when you test constructs within a structural model (Brown, 2006; Chin, 1998; Zwicker et al., 2008). It is recommended to access the reliability using the average variance extracted (AVE), a measure of total variance captured by the construct in relation to the total variance due to measurement error (Netemeyer et al., 2004).

Discriminant validity requires that a measure does not present highly correlated with those that she was supposed to diverge (Netemeyer et al., 2004). Discriminant validity was verified by the criterion employed by Zwicker et al. (2008), which, according to the authors was suggested by Fornell and Larcker (2010) and Chin (1998), which consists of the comparison of the correlation between the latent variables (LVs) with the AVE of each one of them. It is expected that the correlation between an LV and the other is always smaller than its AVE, which represents the relationship between an LV and their indicators.

By inserting the answers of the survey on the structural model originally proposed, we ran PLS algorithm into the Smart PLS software, by removing in every iteration any LV that had a load less than 0.7.

4. Results

The PLS model was run with all variables with loadings below 0,7 were removed from the model. The manifest variables kept in the model were shown in Table 3.

After inserting the responses in the model and running the Structural Equations Model accordingly with the description above, the final model obtained was the one described in Fig. 2.

As it can be seen in the model quality criteria in Table 4, the model quality is acceptable, and so are the latent variables correlations, as shown in Table 5.

Finally, evaluating the statistical significance of each path of the model, the t values, and p-values in Table 6 were obtained.

As it can be noticed by revising Table 6, this model shows significant relationship between Project Management, Six Sigma Method and Project Manager Competencies with both perceived ($R2 = 62\%$, same as model B) and measured project Success, considering not only financial measured results ($R2 = 8.7\%$), but also measured process performance improvement ($R2 = 1.2\%$). This model shows a relationship of Project Manager Competencies with Six Sigma Method ($R2 = 43\%$) and Project Management ($R2 = 20\%$) either, which could be interpreted as the project manager competencies acting as an enabler of the other characteristics.

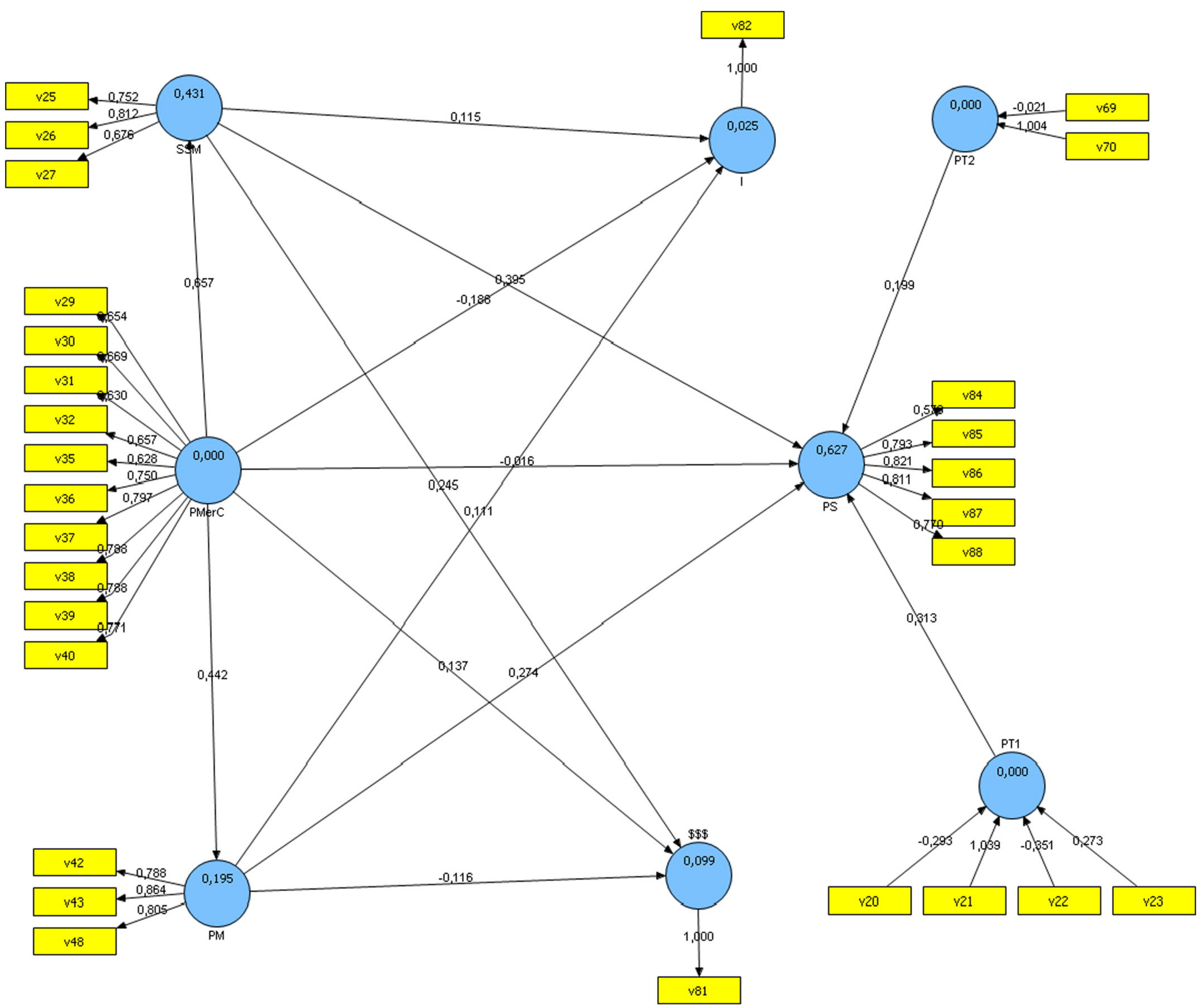

Fig. 2. Path diagram for the model.

Table 4
Quality criteria for the model.

	AVE	Composite reliability	R Square	Cronbach's alpha	Communality	Redundancy
$$$	1.0000	1.0000	0.0990	1.0000	1.0000	−0.0243
I	1.0000	1.0000	0.0247	1.0000	1.0000	0.0045
PM	0.6723	0.8601	0.1953	0.7617	0.6723	0.1226
PMerC	0.5131	0.9126	0.0000	0.8935	0.5131	0.0000
PS	0.5759	0.8699	0.6272	0.8108	0.5759	0.1454
PT1	0.0000	0.0000	0.0000	0.0000	0.1933	0.0000
PT2	0.0000	0.0000	0.0000	0.0000	0.5132	0.0000
SSM	0.5608	0.7921	0.4312	0.6098	0.5608	0.2252

Table 5
Latent variable correlations for the model.

	$$$	I	PM	PMerC	PS	PT1	PT2	SSM
$$$	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
I	0.5749	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PM	0.0462	0.0758	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PMerC	0.2470	−0.0635	0.4420	1.0000	0.0000	0.0000	0.0000	0.0000
PS	0.3049	0.1288	0.6012	0.4905	1.0000	0.0000	0.0000	0.0000
PT1	0.2160	0.0316	0.3180	0.1794	0.4735	1.0000	0.0000	0.0000
PT2	0.1829	0.0272	0.3550	0.3485	0.5002	0.3214	1.0000	0.0000
SSM	0.2873	0.0376	0.4152	0.6567	0.5626	0.0304	0.2743	1.0000

5. Discussion

Overall, the results indicate that Six Sigma project performance is statistically and positively impacted by the efforts on the three constructs explored in this research — Six Sigma Method (H1), Project Management (H2) and the Project Manager competencies (H3). This study is consistent with both Shafer and Moeller (2012) and Swink and Jacobs (2012) as it shows that the extension of Six Sigma implementation is related to project success.

However, the magnitudes of the effects differ according to the project performance variable. For the three dependent latent variables related to performance — project success perception (PS), quality improvement (I) and Financial Returns ($$$), just PS present strong effect (63%), for the others the effect is small 3% and 10%, respectively.

Moreover, our study draws upon contingency theory to explore in the model the effect of project type on project performance, reviling a significant impact, i.e., when project type is less complex, their performance is enhanced. The model also shows that Project Type has a significant association with project results, both perceived as measured. This is consistent with Nair et al. (2011), showing that project context can affect performance. These findings are aligned with the PM literature highlighting that suggests the impact of complexity on project performance (Shenhar and Dvir, 2007; Carvalho et al., 2015).

Exploring each of the studied constructs, the only one that has significant impact on the three dependent performance variable studied is the Six Sigma Method (SSM), which impact on project success perception (PS) and also on quality improvement (I) and on Financial Returns ($$$). The importance of Six Sigma Method to the long-term results can be justified by Clegg et al. (2010), which state that the point of using DMAIC meta-routine is to provide permanent results.

The Project Management (PM) is significantly related with I and PS but not for $$$. As suggested by Six Sigma literature (Carvalho and Rabechini Jr., 2011, Zu et al., 2008), Six Sigma program is led by projects; thus, linking both bodies of knowledge seems to be an fruitful room for future research agenda and the insights of this research shows that the relation of PM and project performance in Six Sigma context should be in-depth understood.

Table 6
T-values and p-values for the paths for model.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	Standard error (STERR)	T Statistics (|O/STERR|)	p-Value	R^2	R^2Aj.
PM → $$$	−0.1164	−0.1202	0.0927	0.0927	1.2556	0.2096	10%	9%
PMerC → $$$*	0.2470	0.2530	0.0697	0.0697	3.5424	0.0004	10%	
SSM → $$$*	0.2455	0.2558	0.0749	0.0749	3.2762	0.0011	10%	
PM → I*	0.1112	0.1299	0.0433	0.0433	2.5692	0.0103	3%	1%
PMerC → I	−0.0635	−0.0473	0.0725	0.0725	0.8750	0.3818	3%	
SSM → I*	0.1149	0.1239	0.0499	0.0499	2.3039	0.0214	3%	
PM → PS*	0.2738	0.2698	0.0681	0.0681	4.0203	0.0001	63%	
PMerC → PS*	0.3648	0.3688	0.0559	0.0559	6.5309	0.0000	63%	
PT1 → PS	0.3131	0.2437	0.2150	0.2150	1.4562	0.1457	63%	62%
PT2 → PS*	0.1995	0.1907	0.0585	0.0585	3.4075	0.0007	63%	
SSM → PS*	0.3949	0.3832	0.0686	0.0686	5.7554	0.0000	63%	
PMerC → SSM*	0.6567	0.6603	0.0535	0.0535	12.2822	0.0000	43%	43%
PMerC → PM*	0.4420	0.4515	0.0488	0.0488	9.0626	0.0000	20%	20%

The Project Manager competencies (PMer) is significant related with $$$ and PS but not for I. It is worth noting that for PMer we intentionally studied its effects also on SSM (H4) and PM (H5) latent variables and the results show a significant impact on both, with a moderate effect on PM (20%) and a strong effect on SSM (45%). Thus, the model is also consistent with Gutiérrez et al. (2012), by showing that the role of project leaders can indeed generate organizational learning, especially about Six Sigma Method. In PM literature, the project manager competencies have been studied as in Archibald (2003), Chang Dong and Zai (2004), Kumar and Antony (2008) and Takey and Carvalho (2015), that describing critical success factors, points intellectual and managerial competencies of the project leaders among them, which brings us to the discussion of what should be those competencies. Several authors show the importance of careful selection of project leaders in Six Sigma context in function of their skills as leaders (Johnson and Swisher, 2003; Zu et al., 2008). However, the exact characteristics needed for the Six Sigma project leader have not been described in Six Sigma literature. We, therefore, sought in Project Management literature, a more detailed description of the behavioral characteristics required of the project leader. The leader or project manager has the role of coordinating the work of the team for the development of the work on the project in search of the best result. Such a role requires coordination of project leader as much technical knowledge on the subject of design, as behavioral skills that will facilitate the conduct of the project. According to Shtub and Globerson (1994), the required competencies of the project leader refers to leadership, negotiation, and technical skills. While the technical expertise required may vary from project to project, the behavioral competencies are similar to the projects.

Another way to organize the roles of the project leader is to separate the technical and managerial roles, according to the Mintzberg (1975) of the transactional leader roles and continuous transformation of Bass (1985).

According to Sommerville and Langford (1994), the sources of stress and conflict in projects may be related to the type of recognition, to industry, to the actions of the team involvement and management style of the leader. The last two factors are directly related to the characteristics of the project leader. In his book, Picq (2011) cites the need for the project manager to have the flexibility to change your management style according to the time of the project, for example, passing the persuasive style when authoritarian in a time of crisis or stalemate that could jeopardize the project.

Those factors were found more important than some traditional success factors such as training and education. The fact that having a fully dedicated project manager with behavioral management skills, supported by the top management, is more important than having extensive training programs, relates with Goh (2010) statement that the Six Sigma program benefit is less related to specific tools or having a very deep statistical approach, and more related with how well the organization can appropriate from the strategic benefit of the project portfolio.

6. Conclusions

This study has a noteworthy contribution to Six Sigma literature by presenting a structural model that shows the significant impact of Six Sigma Method, Project Management and the Project Manager competencies on project performance. Data was gathered in real-life projects and their performance of industrial and service sectors and in two countries Brazil and Argentina.

Project Manager Competencies was one of the latent variables that stood out because it impacts not only project performance but also reinforce the Six Sigma Method and Project Management. Moreover, this study confirms the contingency theory by identifying the significant effect of project type on project performance.

The managerial implications of this study are that it is not enough to ensure Six Sigma Method and Six Sigma Project Management if the organization does not have the correct professionals to the initiative, demanding more attention of companies on the Six Sigma leader selection and training process. Besides, it shows that the efforts on Six Sigma method and Project Management results on better project performance.

The limitations of this study are related to the sampling process, which is non-probabilistic, the geographic limitation (Brazil and Argentina) and the self-reported nature of the responses, which was mitigate by the documental phase of the research approach.

For future research agenda, we suggest, in order to understand the differences between short term and long term results, an analysis of the measurable results of a Six Sigma project portfolio, and also fostering the relation between PM and Six Sigma literatures in the project level of analysis.

Conflict of interest

There is no conflict of interest.

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References

Antony, J., 2006. Six sigma for service processes. Bus. Process. Manag. J. 12, 234–248.

Antony, J., Bañuelas, R., 2002. Key ingredients for the effective implementation of six sigma program. Meas. Bus. Excell. 6, 20–27.

Antony, J., Desai, D.A., 2009. Assessing the status of six sigma implementation in the Indian industry: results from an exploratory empirical study. Manag. Res. News 32, 413–423.

Antony, J., Antony, F.J., Kumar, M., Cho, B.R., 2007a. Six sigma in service organisations factors. Int. J. Qual. Reliab. Manag. 24, 294–311.

Antony, J., Antony, F.J., Kumar, M., Cho, B.R., 2007b. Six Sigma in service organizations: benefits, challenges and difficulties, common myths, observations and success factors. Int. J. Qual. Reliab. Manag. 24, 294–311.

Archer, N.P., Ghasemzadeh, F., 1999. An integrated framework for project portfolio selection. Int. J. Proj. Manag. 17, 207–216.

Archibald, R.D., 2003. Managing High Technology Programs and Projects. Wiley & Sons, New Jersey.

Arumugan, V., Antony, J., Kumar, M., 2013. Production economics linking learning and knowledge creation to project success in six sigma projects : an empirical investigation. Int. J. Prod. Econ. 141, 388–402.

Atkison, R., 1999. Project management : cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. Int. J. Proj. Manag. 17, 337–342.

Bass, B.M., 1985. Leadership and performance beyond expectations. Free Press, New York.

Basu, R., 2014. Managing quality in projects: an empirical study. Int. J. Proj. Manag. 32, 178–187.

Berssaneti, F.T., Carvalho, M.M., 2015. Identification of variables that impact project success in Brazilian companies. Int. J. Proj. Manag. 33, 638–649.

Bertels, T., Patterson, G., 2003. Selecting six sigma projects that matter. Six Sigma Forum Mag. 3, 13–17.

Bhote, K.R., 2002. The Ultimate Six Sigma: Beyond Quality Excellence. AMACOM, New York.

Brady, J.E., Allen, T.T., 2006. Six sigma literature: a review and agenda for future research. Qual. Reliab. Eng. Int. 22, 335–367.

Breyfogle, F.W., 1999. Implementing six sigma: smarter solutions using statistical methods. John Wiley & Songs, New Jersey.

Brown, T.A., 2006. Confirmatory Factor Analysis for Applied Research. The Guilford Press, New York.

Brue, G., 2002. Six Sigma for Managers. McGraw-Hill, New York.

Brun, A., 2011. Critical success factors of Six Sigma implementations in Italian companies. Int. J. Prod. Econ. 131, 158–164.

Byrne, G., Norris, B., 2003. Drive Baldrige level performance. Six Sigma Forum Mag. 2, 13–21.

Carvalho, M.M., 2002. Selecionando Projetos Seis Sigma. In: Rotondaro, R.G. (Ed.), Seis Sigma: estratégia gerencial para melhoria de processos, produtos e serviços. Atlas, São Paulo.

Carvalho, M.M., Rabechini JR, R., 2011. Construindo Competências para gerenciar projetos. Editora Atlas, 3ª edição, São Paulo, p. 422.

Carvalho, M.M., Rabechini Jr., R., 2015. Impact of risk management on project performance: the importance of soft skills. Int. J. Prod. Res. 53, 321–340.

Carvalho, M.M., Ho, L.L., Pinto, S.H.B., 2007. Implementação e difusão do programa seis sigma no Brasil. Revista Produção 17, 486–501.

Carvalho, M.M., Patah, L.A., Bido, D.S., 2015. Project management and its effects on project success: cross-country and cross-industry comparisons. Int. J. Proj. Manag. 33, 1509–1522.

Chakrabarty, A., Chuan, T.K., 2009. An exploratory qualitative and quantitative analysis of Six Sigma in service organizations in Singapore. Manag. Res. News 32, 614–632.

Chang Dong, K.B., Zai, L., 2004. A Study of Critical Success Factors of Information System Project in China. PMI Research Conference, pp. 1–15.

Chin, W.W., 1998. The Partial Least Squares Approach to Structural Equation Modeling. In: Marcoulides, G.A. (Ed.), Modern Methods for Business Research. Mahwah, New Jersey.

Cho, J.H., Lee, J.H., Ahn, D.G., Jang, J.S., 2011. Selection of Six Sigma key ingredients (KIs) in Korean companies. TQM J. 23 (6), 611–628.

Choo, A.S., Linderman, K.W., Schroeder, R.G., 2007. Method and psychological effects on learning behaviors and knowledge creation in quality improvement projects. Manag. Sci. 53, 437–450.

Clegg, B., Rees, C., Titchen, M., 2010. A study into the effectiveness of quality management training: a focus on tools and critical success factors. TQM J. 22, 188–208.

Coronado, R.B., Antony, J., 2002. Critical success factors for the successful implementation of six sigma projects in organisations. TQM Mag. 14, 92–99.

De Mast, J., Lokkerbol, J., 2012. An analysis of the Six Sigma DMAIC method from the perspective of problem solving. Int. J. Prod. Econ. 139, 604–614.

De Wit, A., 1988. Measurement of project success. Int. J. Proj. Manag. 6, 164–170.

Dedeke, A., 2002. What Makes Six Sigma Work. Virtualbookworm.com Publishing.

Desai, D.A., Antony, J., Patel, M.B., 2012. An assessment of the critical success factors for Six Sigma implementation in Indian industries. Int. J. Product. Perform. Manag. 61, 426–444.

Firka, D., 2010. Six Sigma: an evolutionary analysis through case studies. TQM J. 22, 423–434.

Fornell, C., Larcker, D.F., 2010. Evaluating structural equation models with unobservable variables and measurement error. J. Mark. Res. 18, 39–50.

Ghosh, M., Sobek, D., 2002. Effective Metaroutines for Organizational Problem Solving. Mechanical and Industrial Engineering Department. Montana State University, Bozeman, MT, pp. 1–33.

Gijo, E.V., Rao, T.S., 2005. Six sigma implementation — hurdles and more hurdles. Total Qual. Manag. Bus. Excell. 16, 721–725.

Goh, T.N., 2002. A strategic assessment of six sigma. Qual. Reliab. Eng. Int. 18, 403–410.

Goh, T.N., 2010. Six triumphs and six tragedies of six sigma. Qual. Eng. 22, 299–305.

Goh, T.N., Xie, M., 2004. Improving on the six sigma paradigm. TQM J. 16, 235–240.

Goldstein, M.D., 2001. Six sigma program success factors. ASQ Six Sigma Forum Mag. 1, 36–45.

Gutiérrez, L.J.G., Bustinza, O.F., Molina, V.B., 2012. Six sigma, absorptive capacity and organisational learning orientation. Int. J. Prod. Res. 50, 661–675.

Hahn, G.J., 2005. Six Sigma: 20 key lessons learned. Qual. Reliab. Eng. Int. 21, 225–233.

Hair Jr., J.F., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L., 2009. Análise multivariada de dados. Bookman, Porto Alegre.

Hair, J.F., Hult, G.T.M., Ringle, C.M., Sarstedt, M., 2014. A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM). Sage, Thousand Oaks.

Harry, M.J., 1998. Six sigma: a breakthrough strategy for profitability. Qual. Prog. 31, 60–65.

Harry, M.J., 2000. A new definition aims to connect quality with financial performance. Qual. Prog. 33, 64–66.

Harry, M., Schroeder, R., 2000. Six Sigma: The New Breakthrough Management Strategy Revolutionizing the World's Top Corporation. Currency Doubleday, New York.

Henderson, K.M., Evans, J.R., 2000. Successful implementation of six sigma: benchmarking General Electric company. Benchmarking Int. J. 7, 260–281.

Henseler, J., Ringle, C.M., Sinkovics, R.R., 2009. The Use of Partial Least Squares Path Modeling in International Marketing. In: Sinkovics, R.R., Ghauri, P.N. (Eds.), New Challenges to International Marketing. Emerald.

Hilton, R.J., Sohal, A., 2012. A conceptual model for the successful deployment of lean six sigma. Int. J. Qual. Reliab. Manag. 29, 54–70.

Hornstein, H.A., 2015. The integration of project management and organizational change management is now a necessity. Int. J. Proj. Manag. 33, 291–298.

Johnson, A., Swisher, B., 2003. How Six Sigma improves R&D. Res. Technol. Manag. 46, 12–15.

Kaynack, H., 2003. The relationship between total quality management practices and their effects on firm performance. J. Oper. Manag. 21, 405–435.

Keller, R.T., 2001. Cross-functional project groups in research and new product development:diversity, communications, job stress and outcomes. Acad. Manag. J. 44, 547–556.

Kim, D.-S., 2010. Eliciting success factors of applying Six Sigma in an academic library: a case study. Perform. Meas. Metrics 11, 25–38.

Krueger, D.C., Parast, M.M., Adams, S., 2014. Six Sigma implementation: a qualitative case study using grounded theory. Prod. Plan. Control 25 (10), 873–889.

Kumar, M., Antony, J., 2008. Comparing the quality management practices in UK SMEs. Ind. Manag. Data Syst. 108, 1153–1166.

Kumar, M., Antony, J., 2009. Longitudinal study on Six Sigma status in UK SMEs. Paper presented at World Conference on Quality Improvement. Minneapolis, United States.

Kumar, M., Antony, J., Douglas, A., 2009. Does size matter for Six Sigma implementation?: findings from the survey in UK SMEs. TQM J. 21, 623–635.

Kwak, Y.H., Anbari, F.T., 2006. Benefits, obstacles, and future of six sigma approach. Technovation 26, 708–715.

Lin, T.-C., Chen, C.-M., Hsu, J.S.-C., Fu, T.-W., 2015. The impact of team knowledge on problem solving competence in information systems development team. Int. J. Proj. Manag. 33, 1692–1703.

Linderman, K., Chandrasekaran, A., 2010. The progress and exchange of knowledge in operations management. J. Oper. Manag. 28, 357–366.

Linderman, K., Schroeder, R.G., Choo, A.S., 2006. Six Sigma: the role of goals in improvement teams. J. Oper. Manag. 24, 779–790.

Linderman, K., Schroeder, R.G., Zaheer, S., Choo, A.S., 2003. Six sigma: a goal-theoretic perspective. J. Oper. Manag. 21, 193–203.

Martens, S.L., 2001. Operationally deploying Six Sigma. Ann. Qual. Congr. 55, 751–755.

Marzagão, D.S.L., Lopes, A.P.V.B.V., Gouvêa, M.A., Carvalho, M.M., 2014. Fatores críticos de sucesso na implementação do programas Seis Sigma: Uma revisão sistemáticadas pesquisas quantitativas. Revista Produção Online 14, 465–498.

Minarro-Viseras, E., Baines, T., Sweeney, M., 2005. Key success factors when implementing strategic manufacturing initiatives. Int. J. Oper. Prod. Manag. 25, 151–179.

Mintzberg, H., 1975. The manager's job: Folklore and fact. Harv. Bus. Rev. 49–61 (July–August).

Nair, A., Malhotra, M., Ahire, S., 2011. Toward a theory of managing context in Six Sigma projects: an action research investigation. J. Oper. Manag. 29, 529–548.

Netemeyer, R.G., Bearden, W.O., Sharma, S., 2004. Scaling Procedures: Issues and Applications. Sage Publications.

Nonthaleerak, P., Hendry, L., 2008. Exploring the six sigma phenomenon using multiple case study evidence. Int. J. Oper. Prod. Manag. 28, 279–303.

Padhy, R.K., Sahu, S., 2011. A real option based Six Sigma project evaluation and selection model. Int. J. Proj. Manag. 29, 1091–1102.

Pande, P.S., Neuman, R.P., Cabanagh, R.R., 2000. Estratégia Seis Sigma: Como a GE, a Motorola e Outras Grandes Empresas estão aguçando Seu Desempenho. Qualitymark, Rio de Janeiro.

Pande, P.S., Neuman, R.P., Cabanagh, R.R., 2001. Estratégia Seis Sigma. Qualitymark, Rio de Janeiro.

Parast, M.M., 2011. The effect of Six Sigma projects on innovation and firm performance. Int. J. Proj. Manag. 29, 45–55.

Petzel, E., 2006. Six Sigma in Finanzinstituten–Noch viele Fragezeichen. Versicherungsbetriebe 38–42.

Pfeifer, T., Reissiger, W., Canales, C., 2004. Integrating six sigma with quality management systems. TQM Mag. 16, 241–249.

Picq, T., 2011. Manager une équipe projet. Dunod, Paris.

PMI Project Management Institute, 2013. A guide to the project management body of knowledge (PMBOK® guide) – Fifth edition. Author, Newtown Square, PA.

Pyzdek, T., 2003. Uma ferramenta em busca do defeito zero. HSM Manag. 38, 63–70.

Ray, G., Barney, J.B., Muhanna, W.A., 2004. Capabilities, business processes, and competitive advantage: choosing the dependent variable in empirical tests of the resource based view. Strateg. Manag. J. 25, 23–37.

Rotondaro, R.G., 2002. Seis sigmas: estratégia gerencial para a melhoria de processos, produtos e serviços. Atlas, São Paulo.

Schroeder, R.G., Linderman, K., Liedtke, C., Choo, A.S., 2008. Six sigma: definition and underlying theory. J. Oper. Manag. 26, 536–554.

Seri, 2002. A manual for six sigma black belt training. Samsung Economic Research Institute. Seoul, Korea, pp. 1–22.

Shafer, S.M., Moeller, S.B., 2012. The effects of six sigma on corporate performance: an empirical investigation. J. Oper. Manag. 30, 521–532.

Sharma, S., Chetiya, A.R., 2010. Six sigma project selection: an analysis of responsible factors. Int. J. Lean Six Sigma 1, 280–292.

Shenhar, A.J., Dvir, D., 2007. Reinventing Project Management: The Diamond Approach to Succesful Growth and Innovation. Harvard Business School Publishing, Boston.

Shtub, A., Globerson, S., 1994. Project Management: Engineering, Technology, and Implementation. Prentice Hall, New Jersey.

Smith, D.J.H., Blakeslee, J., Koonce, R., 2002. Strategic Six Sigma: Best Practice From Executive Suite. Wiley & Sons, New Jersey.

Snee, R.D., 2001. Dealing with the Achilles heel of six sigma initiatives. Qual. Prog. 34, 66.

Snee, R.D., Hoerl, R.W., 2003. Leading Six Sigma — A Step by Step Guide Based on Experience With General Electric and Other Six Sigma Companies. Prentice Hall, New York.

Sommerville, J., Langford, J., 1994. Multivariate influences on the people side of projects: stress and conflict. Int. J. Proj. Manag. 12, 234–243.

Swink, M., Jacobs, B.W., 2012. Six sigma adoption: operating performance impacts and contextual drivers of success. J. Oper. Manag. 30, 437–453.

Takey, S.M., Carvalho, M.M., 2015. Competency mapping in project management: an action research study in an engineering company. Int. J. Proj. Manag. 33, 784–796.

Timans, W., Antony, J., Ahaus, K., Van Splingen, R., 2011. Implementation of lean six sigma in small- and medium-sized manufacturing enterprises in the Netherlands. J. Oper. Res. Soc. 63, 339–353.

Todorović, M.L., Petrović, D.Č., Mihić, M.M., Obradović, V.L., Bushuyev, S.D., 2015. Project success analysis framework: a knowledge-based approach in project management. Int. J. Proj. Manag. 33, 772–783.

Topfer, A., 2007. Six Sigma in Service Und Dienstleistung. In: Topfer, A. (Ed.), Six Sigma. Springer, Berlin.

Yeung, A.C.L., Cheng, T.C.E., Lai, K.-H., 2006. An operational and institutional perspective on total quality management. Prod. Oper. Manag. 15, 156–170.

Zailani, S., Sasthriyar, S., 2011. Investigation on the six sigma critical success factor. Eur. J. Sci. Res. 57, 124.

Zu, X., Fredendall, L.D., Douglas, T.J., 2008. The evolving theory of quality management: the role of six sigma. J. Oper. Manag. 26, 630–650.

Zwicker, R., Souza, C.A., Bido, D.S., 2008. Uma revisão Do Modelo Do Grau de informatização de Empresas: Novas Propostas de estimação e Modelagem Usando PLS XXXII Encontro Da ANPAD.