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The impact of Six Sigma in the performance of a Pollution Prevention program

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ABSTRACT

The diffusion of Pollution Prevention faces organizational barriers as for instance resistance to change, insufficient support from decision-makers, unclear project leadership, insufficient employee accountability and inflexible organizational structures. To understand how to overcome such barriers, the performance of a Pollution Prevention program of a multinational corporation is analyzed. The quantitative analyses of 2096 Pollution Prevention projects conducted between 1995 and 2007 support the conclusion that the performance of the Pollution Prevention program increased after the implementation of the Six Sigma program. Moreover, the analyses of 1906 Pollution Prevention projects and 31,133 Six Sigma projects for cost reduction in 27 countries indicate that in countries where the implementation of Six Sigma is more expressive, pollution is prevented more than in countries with less expressive Six Sigma implementation. In fact, the Six Sigma implementation improved the organizational capability for data based project management. Therefore, comparing six years before and six years after the Six Sigma implementation, the total number of Pollution Prevention projects recognized increased 6.9 times and the total amount of pollution prevented increased by 62%. The qualitative analysis describes how the Six Sigma program interacts with the Pollution Prevention program in the studied company.

1. Introduction

Although the industrial revolution provided significant contributions to the economic development, it also generated negative side effects. In fact, year after year the amount of evidence increases that human industrial activity damages the natural environment [1].

To reduce the negative environmental impact caused by economic activity, Pollution Prevention was created in order to reduce the source of pollution within the transformation process [2].

However, literature reports by practitioners [3–5] and by environmental agencies [6,7] describe organizational barriers as limiting the diffusion and the performance of Pollution Prevention programs. Those barriers regard communication, leadership, conflicts, attitude towards change, flexibility of organizational structures, time and personnel availability, concerns of potential negative impacts of Pollution Prevention projects, information availability on waste reduction opportunities, reward and accountability systems and decision-makers support.

Six Sigma is a systematic method for process improvement focused on financial results that uses statistical and quality management tools. The main differentials of the Six Sigma methodology compared to the Total Quality practices are expert's organizational structure, focus on metrics and a structured problem solving method [8–10].

This research aims to answer the following question: What is the impact of the Six Sigma implementation in the performance of a Pollution Prevention program? To answer this question, a quantitative and qualitative analysis of the interaction between the Pollution Prevention program and the Six Sigma implementation is performed in a multinational company.

The quantitative research describes the performance of the Pollution Prevention program before and after the Six Sigma implementation and also analyzes the Pollution Prevention performance of countries with subsidiary companies that use Six Sigma intensively compared to those that use Six Sigma less intensively. In addition, the qualitative analysis describes how the Six Sigma implementation integrates with the Pollution Prevention

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program, in order to increase the ability to conduct projects for reducing the source of pollution.

2. Pollution Prevention

Pollution Prevention is an environmental management approach that reduces the source of pollution by improving the efficiency in the use of resources as energy, materials and water. Thus, most frequently, Pollution Prevention is used not for environmental legislation compliance, but for cost reduction to improve the business' financial performance [11].

The United States Environment Protection Agency (EPA) defines Pollution Prevention as [12]:

> *'…reducing or eliminating waste at the source by modifying production processes, promoting the use of non-toxic or less-toxic substances, implementing conservation techniques, and re-using materials rather than putting them into the waste stream.'*

For this purpose, Pollution Prevention methods include equipment modifications, process modifications, products reformulation, substitution of raw materials and improvements in housekeeping, maintenance and training [12].

Between 1970 and 1984, many environmental laws in United States were created, in order to avoid further contamination of land, air and water. Due to the emphasis on command and control mechanisms, this period is also known as the 'Compliance Era'. Around 1985 in United States, Pollution Prevention was established as a paradigm shift, since many companies came to understand that pollution is waste of resources and an evidence of inefficiency. This new approach to environmental management was based on voluntary programs. Pollution Prevention was pioneered by companies as 3 M, Dow Chemical, Du-Pont, and Xerox, which reported economic benefits resulting from pollution reduction [13].

In addition to saving direct costs and reducing environmental impact, Pollution Prevention projects also provide indirect benefits as reducing expenditures related to health and safety issues and decreasing regulatory costs of hazardous waste disposal [14].

However, the impact of Pollution Prevention programs is often limited by obstacles in the implementation process. Cagno et al. analyzed 134 Pollution Prevention projects in different companies and different countries and found that most projects in fact provide significant pollution reductions by implementing new and cleaner technologies or by improving the production process. However, most of the studied projects did not use systematic techniques and were apparently not completely integrated in the management process [11].

The practitioner literature describes numerous organizational barriers to implement Pollution Prevention [3–5]:

- Insufficient decision-makers support to Pollution Prevention
- Organizational structures separating environmental decisions
- Lack of clarity about who should take on the leadership role in Pollution Prevention projects
- Resistance to change
- Insufficient employee accountability mechanisms
- Reward systems not focused on Pollution Prevention
- Fear that a Pollution Prevention project may jeopardize product quality
- Lack of information to recognize an opportunity for waste reduction
- Insufficient infra-structure to support Pollution Prevention plans

Environmental agencies also report organizational barriers to Pollution Prevention Programs [6,7]:

- Poor internal communication
- Conflicts and resistance to change
- Inflexible organizational structure
- Limited financial resources for capital improvements
- Insufficient availability of time and personnel
- Concern that manufacture process changes negatively impact product quality
- Concern of negative customers' perception about the product
- Fear that the stability of the production system may be negatively changed by the Pollution Prevention project.

3. Six Sigma

The Six Sigma methodology is defined as 'an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.' [8].

Motorola created the Six Sigma methodology in 1986, in order to increase its competitiveness against Japanese companies in the electronics industry by improving the quality levels [15]. The name of the Six Sigma methodology is derived from the Greek alphabet symbol utilized in statistics for standard deviation, a measurement to quantify variation and process inconsistency [17].

Although Six Sigma is used by numerous companies worldwide, it has been criticized by those who claim that Six Sigma does not provide a new contribution to organizations and is only a repackaging of conventional quality management practices [18,19].

For a long period of time, the majority of the available literature about Six Sigma was limited to books published by practitioners [16,17] and a reduced number of academic articles about this methodology [9].

Recently, however, academic articles have been published, for example in the *Journal of Operations Management*, using the scientific approach to demonstrate the distinctive contributions of the Six Sigma methodology in the companies.

A study using grounded theory analyzed the Six Sigma implementation program in a manufacturing company and in a service company. It found that, in relation to the traditional Total Quality practices, the Six Sigma methodology innovated by intensively integrating statistical tools to quality management tools in order to compose a structured method for business process improvements [20]. Moreover, this qualitative research identified that companies create an organizational structure of Six Sigma specialists, who participate in intensive training in statistical and quality management tools. The Six Sigma methodology is different from Total Quality due to its focus on financial business results and use of metrics to quantify the performance of business processes. Finally, the researchers concluded that the use of statistical tools is obviously more intensive in projects with unknown root cause of the problems, than in projects, in which the problems' root cause was identified in advance [20].

A quantitative research using structural equations based on a sample of 226 companies in the USA demonstrated that Six Sigma is different from the Total Quality traditional practices, because it has a structured method for problem solving, it is focused on metrics and because it has a specialized organizational structure [10]

The following roles and responsibilities compose the Six Sigma organizational structure (Fig. 1) [17]:

- The main role of Six Sigma is the expert project manager called 'Black Belt', in analogy to the oriental martial arts that define different belts to indicate the proficiency level. This project manager is responsible to lead a project and to statistically

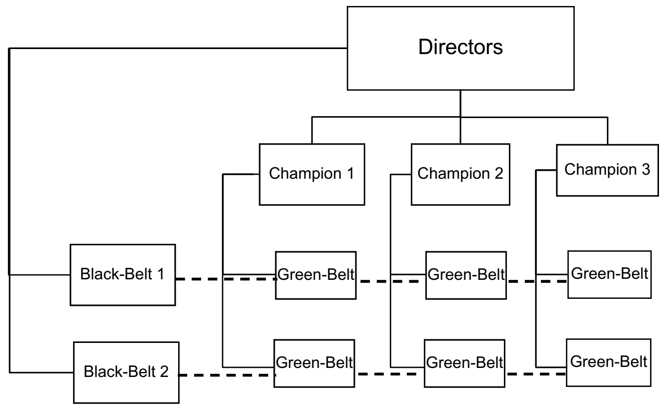

Fig. 1. The Six Sigma organizational structure.

validate the independent variables (project Xs) that most impact the project dependent variable behavior (project Y).

- The functional managers have the role of project 'Champions' for the Six Sigma initiative and are responsible to remove every organizational barriers that the project leader and the project team identify during the project.
- Employees that keep in their functional organizational structure and are also trained to lead less complex Six Sigma projects are denominated 'Green Belts'.

In a Six Sigma program, Black Belts and Green Belts use a structured procedure for problem solving, represented by the Define–Measure–Analyze–Improve–Control (DMAIC) stages for process improvement [8]. Thus, the Six Sigma project is organized in phases of project definition, current performance measurement, and analysis of the independent variables, independent variables improvements and independent variables control procedures [17]:

- Define – A project begins with a statement about the problem to be solved.
- Measure – In this phase, the team measures the actual performance of the project dependent variables (Ys).
- Analyze – In the analytical phase, the project team identifies the potential independent variables (project Xs), prioritizes them and quantifies their explaining power for the Y behavior.
- Improve – Once the independent variables (project Xs) are proved in the Analyze phase, the team manipulates the Xs, in order to experimentally optimize the process parameters in a prototypic solution.
- Control – Finally, the project team creates new work procedures and new roles and responsibilities, in order to ensure continuous maintenance of the improved performance.

In each of those phases, the Six Sigma program specifies the quality management methods and the statistical techniques to use [8].

4. Methodology

The objective of this research is to understand if the performance of the Pollution Prevention program of a multinational company improved with the implementation of the Six Sigma methodology.

In order to accomplish this research goal, it is necessary to validate quantitatively if due to the Six Sigma implementation, the amount of pollution prevented increased. If this relationship is confirmed, then it is also necessary to use a qualitative research approach to explain how the Six Sigma methodology interacts with the Pollution Prevention program.

The analyzed company was founded more than a century ago in the United States. Today, this company comprises internationally more than seventy thousand employees and manages more than thirty business units, multiple technological platforms, more than a hundred plants, owns companies in more than sixty countries and has sales in almost two hundred countries.

The significant product diversity of this company generates considerable variability of the amount of pollution prevented monthly in the Pollution Prevention program, since the different product lines have very different material weights.

The Pollution Prevention program in the analyzed company completed thirty two years of existence in 2007 with 3342 projects recognized and resulted in the prevention of more than 1.1 million tons of pollution economizing over US$ 1 billion (accounting only the results of the first year of each Pollution Prevention project).

This multinational company was chosen because it manages a Pollution Prevention program with decades of experience, operating in plants worldwide. Moreover, in this company, it is possible to observe the interaction between the Pollution Prevention program and the Six Sigma methodology since 2001.

The data was obtained from the analyzed multinational company Pollution Prevention program database, in which are registered: all successfully implemented and recognized Pollution Prevention projects, the submission month of each project, the amount of pollution prevented (this amount refers only to the first year of pollution prevented by each project) and whether the project was conducted by the Six Sigma organizational structure and methodology.

In this database, a 'submitted project' is a project already implemented. In addition, a 'recognized project' is an implemented project approved by the committee responsible for the Pollution Prevention Program, because the project was considered to be aligned with the program's criteria of reducing environmental impacts and generating economic benefits.

The statistical analysis uses non-parametric methods [21] and time series [22].

The data in this research comprises 156 monthly observations (form January 1995 to December 2007) from the number of submitted Pollution Prevention projects and the amount of pollution prevented (in tons). Eight months were observed with no projects submitted within this period, thus the number of observations in the sample is 148 months.

Projects of one of this company's plant that processes industrial minerals were excluded, because its material weights are disproportionally different from the material weights of the other plants and divisions. Thus, it was decided to omit the projects of the industrial-minerals operations, in order to avoid analysis distortions.

5. Results and analyses

Along the more than thirty years of the Pollution Prevention (P2) program, the number of recognized projects changed according to the different phases of the program (Fig. 2).

The Pollution Prevention program was introduced in 1975. Until 1980, the annual number of recognized projects in the program maintained a constant pattern. From 1981 to 1985, the number of projects increased consistently every year following the career development of the program's founder, who was promoted many times until he became a vice president of the company. From 1986 to 1995, after the retirement of the program's founder, the Pollution

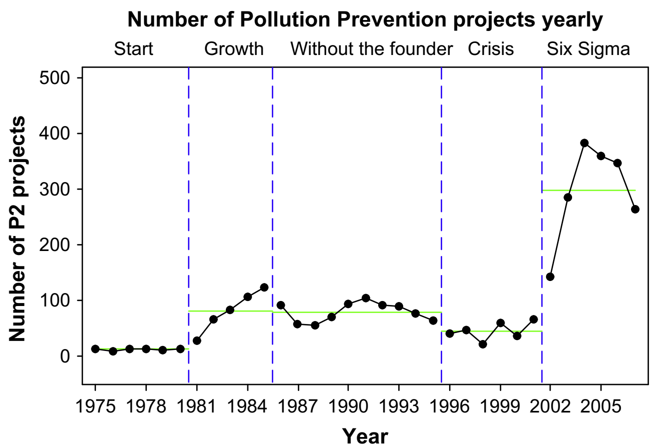

Fig. 2. The development of the Pollution Prevention program with the yearly number of recognized projects.

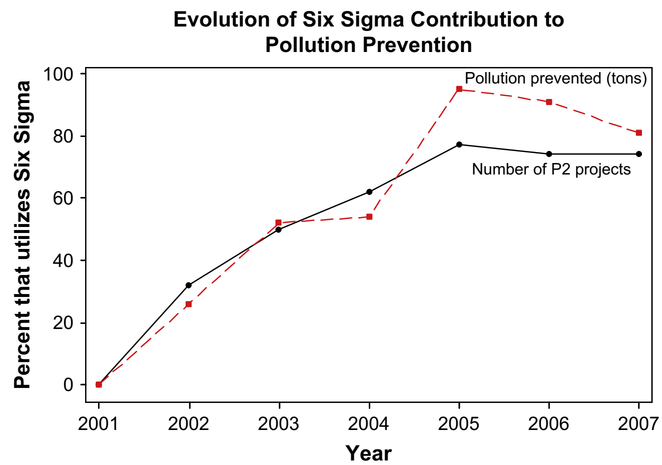

Fig. 3. Percentage of the number of Pollution Prevention projects and of the amount of pollution prevented using Six Sigma.

Prevention program maintained a stable performance. The years between 1996 and 2001 were a period of crisis, in which the number of annual projects clearly decreased. Finally, after the implementation of Six Sigma in 2001, the Pollution Prevention program recognized a significantly more expressive number of projects yearly.

In fact, the percentage of the Pollution Prevention projects that used Six Sigma increased in the first five years of the Six Sigma program and maintained stable thereafter. In addition, the percentage of the amount of pollution prevented with Six Sigma also increased in the first five years and decreased less intensively in 2006 and 2007 (Fig. 3).

The following analysis is based on 2096 projects submitted along 148 months from 1995 to 2007. Those projects were conducted in the analyzed company's plants located in all continents, thus the scope of the analysis is a global scope of the operations.

The statistical analysis aims to validate the following hypothesis: The implementation of Six Sigma improves the performance of the Pollution Prevention program.

Over thirteen years of the analyzed company's Pollution Prevention program, from 1995 to 2007, it was observed that the average monthly tons of pollution prevented decreased during the years before the Six Sigma implementation, remained low during the year of the Six Sigma implementation and increased in the years after the Six Sigma implementation (Fig. 4).

The comparative analysis between phases is summarized in the box plot of the monthly pollution prevented by the Pollution Prevention program before and after the Six Sigma implementation (Fig. 5).

In the six years before the Six Sigma implementation, the Pollution Prevention program prevented a total of 82,769 tons of pollution, while in the six years after Six Sigma the aggregated pollution prevented was of 133,864 tons. Thus, comparing the six years before Six Sigma and the six years after Six Sigma, the performance of the Pollution Prevention program increased 62%.

The Kruskal–Wallis test identifies that the monthly tons of pollution prevented by the Pollution Prevention program before Six Sigma is less than the monthly tons of pollution prevented after Six Sigma (p-value = 0.0000).

In fact, the Six Sigma organizational structure and methodology increased the organizational capacity for managing Pollution Prevention projects. The time series of the number of recognized

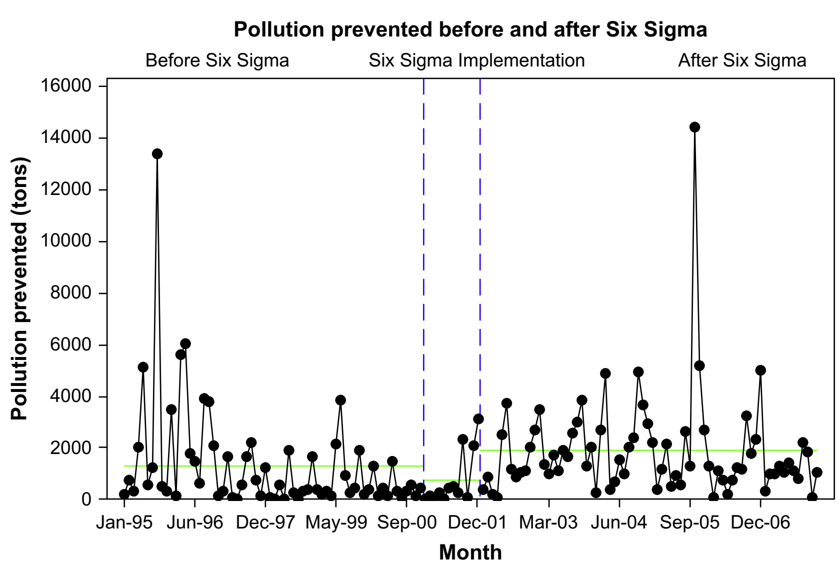

Fig. 4. The amount of pollution prevented monthly in tons before, during and after the Six Sigma implementation.

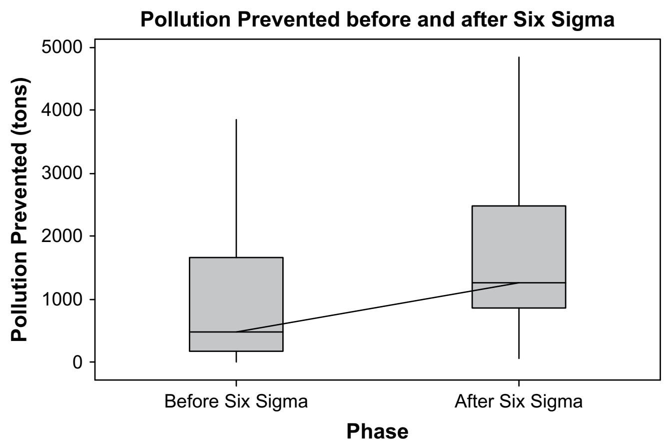

Fig. 5. The monthly amount of pollution prevented before and after the Six Sigma implementation.

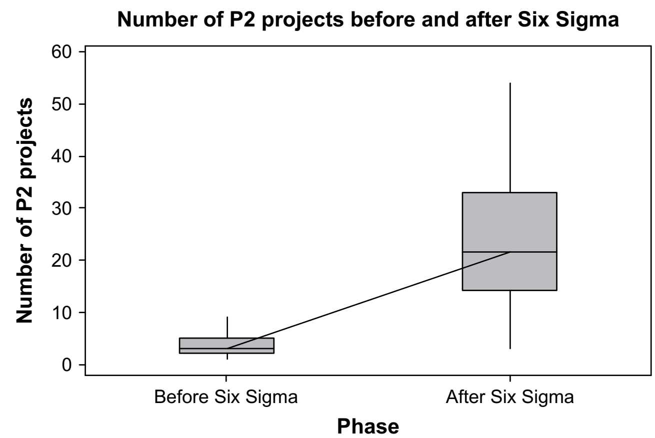

Fig. 7. The monthly number of Pollution Prevention projects before and after the Six Sigma implementation.

Pollution Prevention projects submitted monthly from 1995 to 2007 shows that before Six Sigma and during the Six Sigma implementation, the number of Pollution Prevention projects remained stable and low, while after the Six Sigma implementation, the number of projects increased significantly (Fig. 6).

The aggregated impact of the Six Sigma organizational structure and methodology on the number of Pollution Prevention projects submitted monthly is shown in an additional visual representation in the box plot (Fig. 7).

In the six years before the Six Sigma implementation, the analyzed company submitted 256 recognized Pollution Prevention projects. In the six years after the Six Sigma implementation, 1775 Pollution Prevention projects were submitted. Therefore, the number of Pollution Prevention projects increased 6.9 times after the Six Sigma implementation.

The Kruskal–Wallis test identifies that the monthly number of submitted Pollution Prevention projects before Six Sigma is less than the monthly number of submitted Pollution Prevention projects after Six Sigma (p-value = 0.0000).

In summary, after Six Sigma, the monthly amount of pollution reduced by the Pollution Prevention program increased in average 1.4 times and the median was 2.6 times higher, while the number of recognized Pollution Prevention projects submitted increased in average 6.2 times and the median was 7.2 times higher (Table 1).

The conclusion above states that the performance of the Pollution Prevention program increased as a result of the Six Sigma implementation in 2001. However, a potential risk to this analysis is that different significant events other than the Six Sigma implementation may have also occurred in 2001, causing the amount of pollution prevented to increase.

In order to decrease this bias risk, data from 2001 to 2007 of 1906 Pollution Prevention projects and 31,133 Six Sigma projects for cost reduction is analyzed by comparing 27 different countries, in which the analyzed company operates with manufacturing in its respective subsidiaries.

Firstly, it was analyzed whether subsidiary companies in countries with a more expressive implementation of the Six Sigma program have better performance in the Pollution Prevention program than subsidiary companies in countries with a less significant Six Sigma implementation. As a proxy variable for the expressiveness of a country's subsidiary Six Sigma implementation, the total number of Six Sigma projects for cost reduction between 2001 and 2007 in relation to the respective country's gross domestic product (GDP) was used [23].

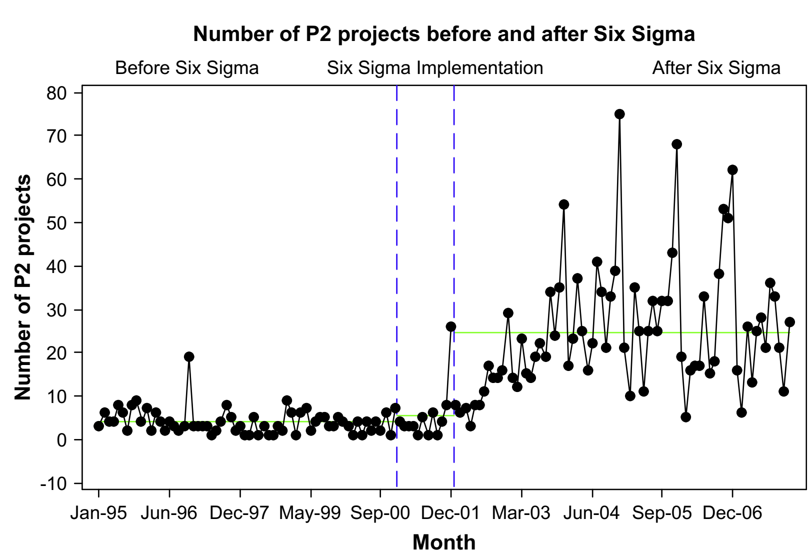

Fig. 6. The monthly number of recognized Pollution Prevention projects submitted before, during and after the Six Sigma implementation.

Table 1
Descriptive statistics of the monthly performance of the Pollution Prevention program before Six Sigma and after Six Sigma.

	Number of P2 projects			Pollution Prevented (tons)		
	Before Six Sigma	After Six Sigma	Increase	Before Six Sigma	After Six Sigma	Increase
Mean	4	24.7	516%	1293	1859	44%
Median	3	21.5	617%	481	1260	162%
StDev	2.9	14.7		2074	1945	

The subsidiary company in Italy, for example, conducted 263 cost reduction Six Sigma projects during this period and this country had a gross domestic product of 2068 billion US$ in 2007, then the relation between those two variables is 0.1 Six Sigma projects/GDP (billions). On the other hand, Singapore's subsidiary company conducted 469 Six Sigma projects for cost reduction and Singapore had a gross domestic product of 153 billion US$, providing a relationship of 3.1 Six Sigma projects for cost reduction/GDP (billions). Thus, the Singaporean subsidiary company has a more expressive Six Sigma program than the Italian one has.

Moreover, the Italian operations reduced 688 tons of pollution in this period, resulting in 0.3 Pollution Prevented (tons)/GDP (billions), while the Singapore operations reduced 1121 tons of pollution, resulting in 7.3 Pollution Prevented (tons)/GDP (billions).

The Kruskal–Wallis test confirmed (p-value = 0.001) that subsidiary companies in countries with more expressive Six Sigma programs, measured by the number of Six Sigma projects for cost reduction/GDP (billions), have better Pollution Prevention performance in tons of pollution prevented/GDP, than subsidiary companies in countries with less expressive Six Sigma programs have (Fig. 8). The median of the amount of pollution prevented in relation to the GDP in countries with an expressive number of cost reduction Six Sigma projects was 22 times the median of the amount of pollution prevented in relation to the GDP in countries with an inexpressive number of cost reduction Six Sigma projects.

Finally, a different proxy variable for the expressiveness of the Six Sigma implementation was analyzed measured by the total Six Sigma program financial gains with cost reduction projects between 2001 and 2007 per subsidiary companies in relation to the respective country's gross domestic product (GDP).

The Kruskal–Wallis test also confirmed (p-value = 0.000) that subsidiary companies with more expressive Six Sigma programs, measured in Six Sigma cost gains (US$)/GDP (millions), have better Pollution Prevention performance in tons of pollution prevented/GDP, than subsidiary companies with less expressive Six Sigma programs have (Fig. 9). And the median of the amount of pollution prevented in relation to GDP in countries with high Six Sigma financial gains was 44 times the median of the amount of pollution prevented in relation to the GDP in countries with low Six Sigma financial gains.

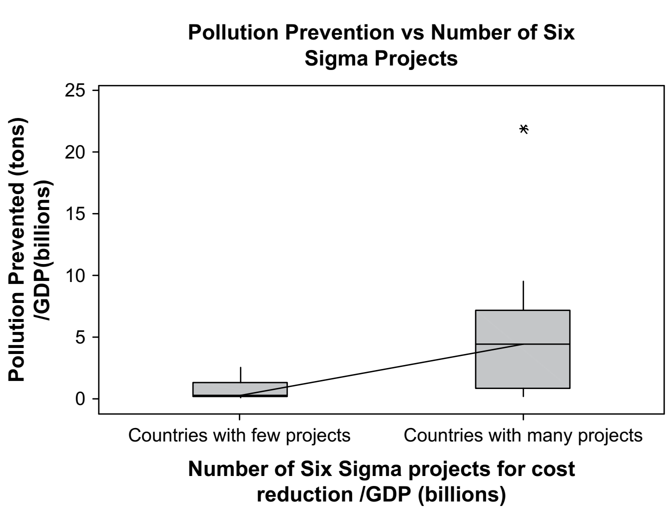

Fig. 8. Amount of pollution prevented in relation to the GDP in countries with more and in countries with less expressive Six Sigma programs measured by the number of cost reduction Six Sigma projects.

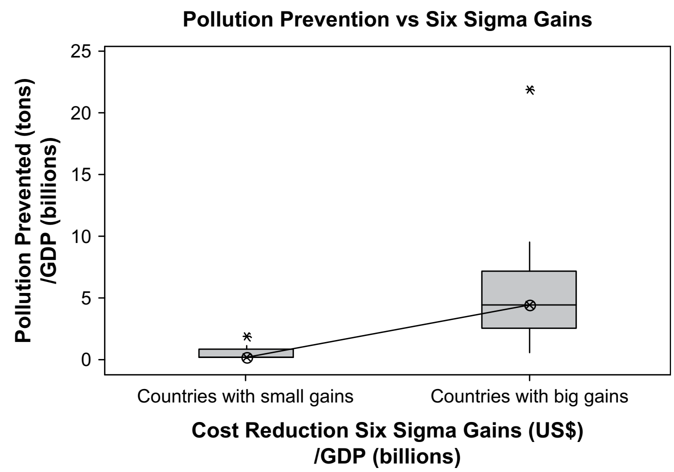

Fig. 9. Amount of pollution prevented in relation to GDP in countries with more and in countries with less expressive Six Sigma programs measured by the Six Sigma cost projects financial gains.

6. Qualitative analysis

Once the relationship between the implementation of the Six Sigma organizational structure and methodology and the performance of the Pollution Prevention program is statistically established, the qualitative analyses explains how the Pollution Prevention program in the analyzed company interacts with the Six Sigma organizational structure and methodology.

Originally, the Pollution Prevention program in the analyzed company consisted of the competence to create an organizational system to transform new project ideas into effectively prevented pollution and reduced costs. In order to conduct this process, the Pollution Prevention program stimulates employees to voluntarily create self-organized project teams, to define the project scope, to measure the current pollution level and to create solutions to reduce the source of pollution. The solutions for Pollution Prevention includes actions as, for example: change of raw materials, technological upgrade, production process modification, recycling, waste reduction, improvements in maintenance and better methods to control emissions. After the solution to reduce the source of pollution is implemented, the Pollution Prevention project team quantifies the pollution prevented and submits the project to the managers of the corporate Pollution Prevention program for approval. If the project is considered successful, then it is officially recognized in a special event and the project is registered in the Pollution Prevention program database (Fig. 10).

With the implementation of the Six Sigma organizational structure and methodology, it was observed that the Pollution Prevention program significantly increased the number of approved Pollution Prevention projects submitted, due to the new organizational capacity for managing projects based on precise data analysis. This new capacity is the result of the ability to implement an organizational culture for project management, by defining an organizational structure with exclusive roles for project

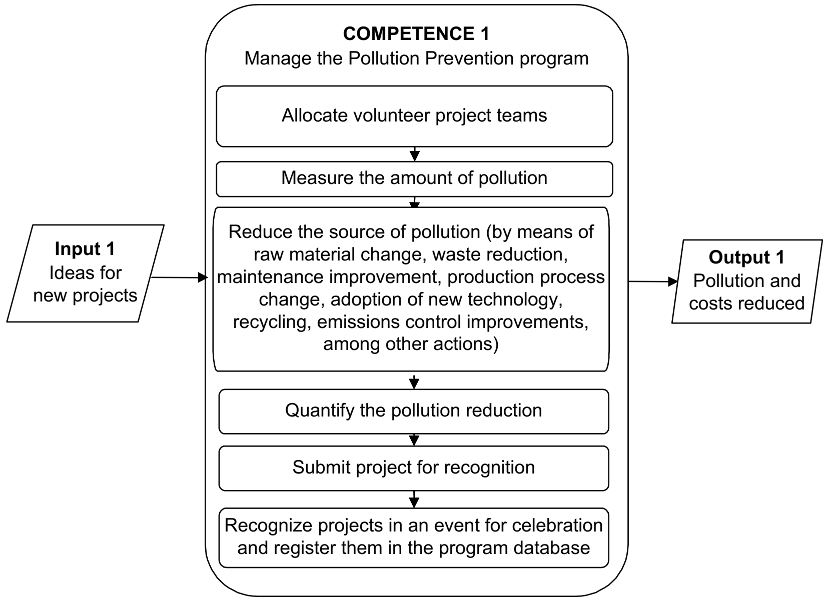

Fig. 10. The original process of the Pollution Prevention program.

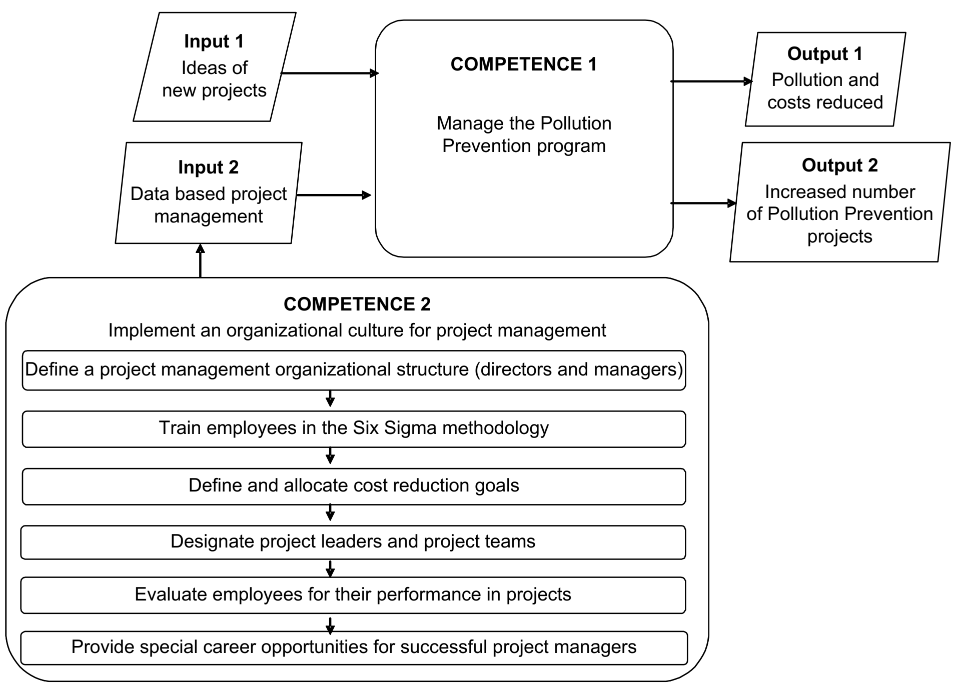

Fig. 11. The connection of the original process of the Pollution Prevention program with the process to implement an organizational culture for project management.

management directors and managers, by training most employees in the Six Sigma methodology, by yearly defining and allocating cost reduction goals, by designating a leader and a team to each project, by evaluating employee performance as project leaders and as members in project teams and by promoting successful project managers to special career opportunities (Fig. 11).

7. Conclusions

The statistical analyses confirmed the hypothesis of this study. In fact, the implementation of the Six Sigma organizational structure and methodology improved significantly the performance of the Pollution Prevention program. In the period after the Six Sigma implementation the total number of Pollution Prevention projects increased 6.9 times and the total tones of pollution prevented increased by 62% in relation to the period before the Six Sigma implementation. In addition, subsidiary companies that achieved a sounder Six Sigma implementation have better Pollution Prevention performance, than those with a less expressive Six Sigma implementation in terms of number of Six Sigma projects for cost reduction and also in terms of financial gains from Six Sigma projects for cost reduction.

Practitioners' and environmental agencies literature report that organizational barriers seriously constrain the performance of Pollution Prevention programs. In this sense, the contribution of this research is to describe the impact of an organizational approach to improve the performance of a Pollution Prevention program. More precisely, this research provides evidence that in the analyzed multinational company the Six Sigma methodology and organizational structure increased the Pollution Prevention program ability to reduce the source of pollution.

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