Application of Six Sigma in Small Company

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***Abstract*--Six Sigma has been used by large companies to improve the performance of their manufacturing processes. However, the interest and the application of this methodology in small and medium size companies is something emerging, despite being little widespread in the literature. This article shows the applicability of Six Sigma in a small Brazilian company, explaining the application strategy and its impacts. The work presents a review about Six Sigma and DMAIC (Define, Measure, Analyze, Improve, and Control) method, which had been mostly successful so far in large companies and is suitable for this case, and shows the particularities of small business that could have some impact in this application. Then, details of the application of Six Sigma with DMAIC in a small company of surface treatment of metal parts are discussed. The article shows the feasibility, applicability, and impact of Six Sigma in this small company, which achieved the reduction of rework in approximately 20% on the zincifying process.**

I. INTRODUCTION

The market of supply and demand is in growing trend with business opportunities broadening and attractive [47]. However, consumers have preferences of better products that fulfill or exceed their expectations, with accessible prices [25]. In this sense, companies need to win by speed, flexibility, and accuracy, applying resources that contribute with the development of effective products [48].

In the search for this high performance, the Six Sigma (6 σ) methodology came to blows disseminated in the growing pace among large companies, mainly the multinationals. This methodology aims to combine statistical methods and quality by reducing the defects and variations in the design, so that promoting the increase of quality of products. However, among small and medium size enterprises (SMEs), the spread of this methodology seems yet to represent the challenge, taking an account a little documented evidence of the implementation of 6 σ in small enterprises [4], [24], especially in the Brazilian enterprises [15]. In spite of having many publications about 6 σ, the majority refers to large companies [3]. It can be cited, as an example, the studies by [1], [6], [12], [13], [40], [41]. Reference [20] states that 6 σ, originally was not planned for SMEs.

Recently, [39] surveyed to identify how 6 σ program was carried out in eleven companies located in the State of Rio Grande do Sul (Brazil) concluding that 91% of these companies were large, being the majority automobile and agricultural sectors. Among existing publications known in Brazil, which refers to 6 σ in the SMEs, can be cited [26], that identified critical factors faced by four enterprises that applied this methodology.

Another study carried out by [15] through the survey, searched to know the factors that influenced the decision for the adoption or not of 6 σ by the SMEs manufacturing car parts. The study concluded that the factors of influence were: managerial conscientiousness, previous competence to lead projects, the amount of resources available, and previous existence of the culture of quality. However, none of these studies show the procedures involved in the practical application of 6 σ in SMEs that can be replicated by the entrepreneurs without hiring external agents.

To 6 σ be applied by the SMEs is necessary that the traditional methodology be adapted to become sustainable. Many authors, such as [4], [5], [20], [30], [50], made suggestions to facilitate the implantation of 6 σ in SMEs, however, credited that the main restrain factor is an excessive cost of the selection to prepare the team. SMEs will face difficulties to train and to have available few qualified clerks, responsible to multiple functions to act in the improvement team, afterwards to wait months for the return of investment.

Regarding to the case study of application of 6 σ in SMEs, it was identified the approach of [22] which present the application in Indian bicycle manufacturing enterprise, that could be adapted to small enterprise. However, papers reporting practical applications in small Brazilian enterprises are not known. Thus, this study was carried out aimed to show the application of 6 σ in small Brazilian enterprise, with details about the strategy utilized in the industrial environment, without specialized external consultancy to explicit the impacts unleashed in short term.

For that, the concepts of 6 σ methodology and particularities of small enterprises are presented, including DMAIC (Define, Measure, Analyze, Improve, and Control) method, selected as the application strategy. The industrial environment is delimited for 6 σ application, in which the stages of DMAIC are applied in simple way, including other process methods as FMEA (Failure Mode Effect Analysis), DOE (Design of Experiments), and others. Aiming to measure the impacts of the application of 6 σ, some performance indicators are monitored before and after, to explicit quantitatively the benefits achieved.

II. METHODOLOGY

Initially the bibliographical review was performed about: 6 σ and the strategy to apply DMAIC, besides mention the characteristics of small enterprises that impact the application of this process. Afterwards, is presented the application of 6 σ, with DMAIC method, in small enterprise of surface

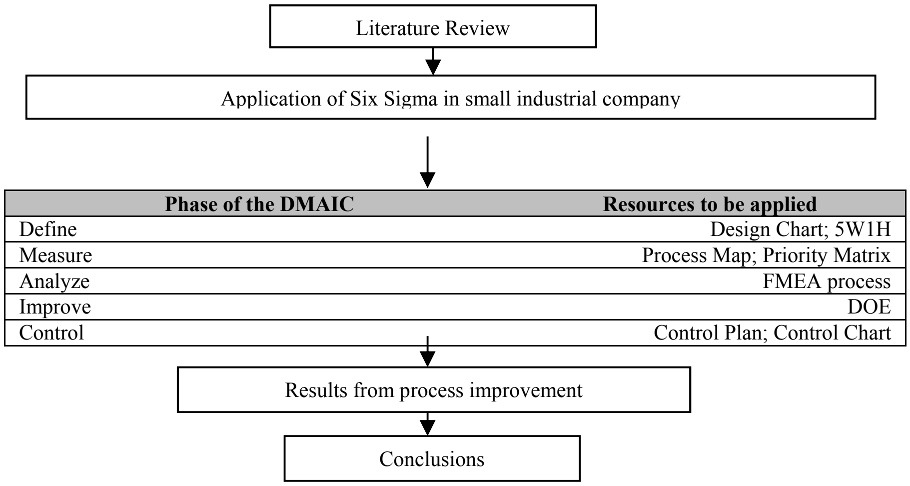

Fig.1. Methodological flow utilized in the work - Source: Elaborated by Authors.

treatment, being limited to the zincifying process, for the case study, as this presents high rates of rework.

Taking an account the peculiarities of small enterprises and the time available to apply 6 σ, only few recommended methods in the literature were applied in this practical industrial case. These were delimited based according to [42] that state as the method more utilized, approved efficacy and low cost of application. These methods and phases of DMAIC in which are applied, including other methodological stages of this survey are presented in Figure 1. Details about DMAIC and resources applied are described in the literature review.

III. THE 6 σ AND THE SMALL COMPANY

The 6 σ presents more recent program of quality management emerged at Motorola in 1987, an American Company, aiming to improve the enterprise performance through the studies with focus in the variability of production processes [21]. This is based in several characteristics of previous models, as a statistical thinking, typical of the time of major emphasis in the quality control, analysis of problems resolution [7]. The 6 σ presents the concern with the use of systematic statistical tools, following the cycle named as DMAIC, which will be detailed afterwards [11], [35]. Despite the Motorola is the forerunner of 6 σ, the methodology earned popularity in 1994, when the president of the General Electric (GE) considered the way to search for high quality and profitability [49].

In the literature is possible to find several approaches regarding to the definition of 6 σ. One defines 6 σ as a set of statistical tools associated quality management, aiming to define structured planning to improve the process [46]. The nomenclature has the origin in statistics, in which the Greek letter "Sigma" (σ) represents the measure of variation in the manufacturing process, also known as standard deviation of the value craved [23]. Statistically, "6 σ" means that, in the centralized normal distribution, can be find six standard deviations between the average and the lower limit of specification (LLS) plus six standard deviations between the upper limit of specification (ULS), results in 1.2 defects per billion of opportunities (DPBO). The graph of this type of centralized normal distribution normal and the levels of Sigma between the average and the specifications limits, which can be regarded as the dimensions of the mechanical part, as an example, is shown in Figure 2.

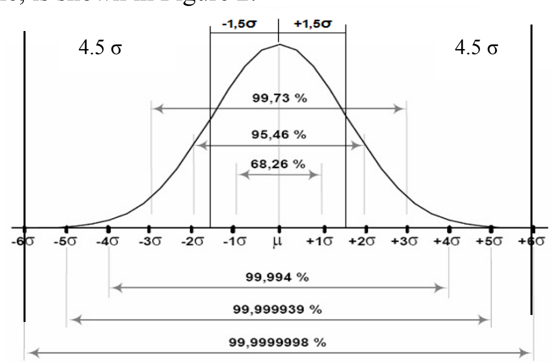

Fig. 2. Graph of centralized normal distribution [45]

Reference [37] states for long term, is difficult to keep centralized process, as presupposed by normal distribution. So that convened the displacement from the nominal average of 1.5 standard deviations. Thus, the process can be considered 6 σ when reaches 4.5 standard deviations between the average and LLS and 4.5 standard deviations between the average and ULS. This way, as can be seen in the Figure 2, when the curve approaches to 4.5 σ in the left and right, the defects practically stabilize and approaches to zero, achieving high degree of quality.

Table 1 relates Sigma level with DPMO (Defects per Million of Opportunities) index, showing the impacts of the costs due to the low quality level in each case.

TABLE 1 – SCALE OF QUALITY

Sigma Level	Maximum Defects per Million (DPMO)	Cost of the low quality (% Sales)
6 Sigma	3.4	<5
5 Sigma	233	5 to 10
4 Sigma	6,210	10 to 15
3 Sigma	**66,807**	**15 to 20**
2 Sigma	308,537	20 to 25
1 Sigma	691,462	>25

Source: Adapted from [31]

According to [16] the meaning of values explicit in the Table 1 indicate that the average of industries operates in the level of quality 3 Sigma which costs from 15% to 20% of invoices in wastages with rework, inspections and other losses.

To estimate DPMO index utilizes the ratio between the number of parts rejected and the number of parts produced, multiplied by one million. For example; if 100 parts is produced and 5 were rejected, consider "5 divided by 100" and multiply these result by one million, resulting in 50 thousand DPMO, that falls within 3 Sigma process. This approach is utilized in processes measured by attributes, separating parts with conformity or non-conformity.

To apply 6 σ, aiming to achieve high level of quality or reduction of defects per million, is necessary to define an adequate strategy for application. According to [34], 100% of the enterprises that applies the 6 σ utilize the DMAIC in some fabrication processes, as already the processes exist. Reference [39], in the survey of 6 σ with eleven enterprises, found that the most applied method was the DMAIC. In the case of new processes, recommend the use of DFSS (Design for Six Sigma), that reach the maximum 39.1% of the cases found in the enterprises. According to [28], despite its popularity, the DMAIC is not more indicated when the scope of the problem is simple and strict. It is recommended for existing processes that present complex positions, involving more than two variables during the operation. Considering the present work focusing on improvement of fabrication process already consolidated, in which involve more than two variables during the execution, only the DMAIC method will be presented.

A. DMAIC Method

The DMAIC method started to be spread with 6 σ by Motorola in the decade of 80´s, popularized by GE, which trained specialists with effort to solve problems in organized manner, supported by quality tools and statistics, with certain degree of complexity. It is applied in five phases, related to own name as: Define, Measure, Analyze, Improve, and Control. These phases guarantee that the companies apply 6 σ in the methodical and disciplined way [3]. Regarding to the resources involved in this improvement of process procedures with 6 σ, according to the survey performed by [39], the most utilized are: FMEA, Process Map, Cause and Effect Diagram, Paretos´s Graph, and Control Charts. However, there are others that could contribute with this type of procedure, which must be utilized according to the needs of the project.

Define Phase

In the first phase of DMAIC defines which fabrication process will be chosen to apply 6 σ. According to [37], definition of the 6 σ team at the beginning is paramount for the success of application, as all methodology is developed by persons. The work team should present the following structure:

Base core – composed by specialized persons in 6 σ, responsible to project since the beginning to the final execution.

a. Members – persons that will integrate the team during determined phase of the project;
b. Experts – persons with specialized knowledge of processes that compound the scope of project aiming to assist the team.

The designations of the roles to be exerted by the team vary according to the training work load, hierarchy in the projects and dedication to the program [3]. They are named as: Sponsors, Champions, Master Black Belts (MBBs), Black Belts (BBs), Green Belts (GBs), Yellows Belts (YBs) and White Belts (WBs), of which last five terms are originated at Unisys Corporation, based in the martial art (karate) [8]. According to [3], [33], they have the following competences:

- Sponsors – are in the top of the team with the responsibility to promote and define the guidelines to implant 6 σ;
- Champions - members of the executive committee, that facilitate to obtain resources and to eliminate barriers to develop improvement of projects;
- Master Black Belts – make a liaison between the general management of the 6 σ project and persons responsible to each improvement of projects;
- Black Belts – lead specific projects. Work with tasks linked to identification of new projects and in the training of GBs. Have formation in statistical methods, quality improvement process, among others;
- Green Belts – dedicate to the improvement, with part time in the project;
- Yellows Belts and White belts – compose as called "shop floor", but are trained to utilize the basic tools of 6 σ that apply to several stages of the projects.

Reference [32] proposed structured team, as presented in the Chart 1, in which are shown basic duty of each charge of responsibility, including the titles utilized within the 6 σ project.

CHART 1 - SIX SIGMA TEAM

Generic Role	Role	Titles within the 6 σ Team
Leadership Council	Enterprise top manager	Quality Council, Enterprise Management Committee
Sponsor	Supervise the Project	Owner of the Manufacturing Process
Implantation Leader	Support Leadership of the Group	6 σ Director, Quality Leader, Master Black Belt
Coach	Consultant that support the team	Master Black Belt, Black Belt
Team Leader/Project	Responsible to 6 σ project, to select the members of the team, define techniques utilized, document results and historic of the project.	Black Belt, Green Belt
Team Member	Collaborators that assist measurement and analysis of the process	Green Belt, Team Member
Owner of the Process	Collaborator responsible to keep improvement after 6 σ	Champion, Green Belt

Source: Adapted from [32]

After built up of the team, next step is to identify the necessity of clients and determine the critical processes. This must be finished by working out one proposal of project to be approved by the top manager.

The proposal of project, also called "Map of Project", according to [32], is the main result of the first phase, and must hold the statement of the problem to be solved, the goal to be achieved, guidelines of the 6 σ team, list of the members of the team and the schedule to be accomplished. In this phase the team also determines the "mission of the project" through the technique of "5W1H" (Who, What, Why, Where, When, How), in which consists to answer the following questions related to the project: "Who?", "What?", "Why?", "Where?", "When?" and "How?".

Measure Phase

This phase aims to determine the status of the stated implantation of 6 σ and the potential sources of variables in the fabrication process. To identify the critical processes, according to [37], is necessary to model the focus process and associated sub-processes, defining the inputs and outputs of each phase, establishing relationship between them classifying the inputs as controlled or not controlled characteristics. For that, more utilized technique is the Process Map. This must be filled by the contribution of all members of 6 σ team, beside the use of existing documents in the company and rely on experience of the collaborators in all hierarchical levels, sometimes with the experience of clients and suppliers. Process Map proposed by [36] is shown in the Figure 3.

Aiming to establish the relationships between inputs X and outputs Y, shown in the Figure 3, have the Matrix of Prioritization, presented in the Figure 4, that utilize the Process Map as the main source of information. The filling of this Matrix starts with correlation of input variables of the process in the second column and the main variables of output in second line. For each variable of output must be attributed a rate of importance of 1 to 10, according to the criteria to be established by the team. The team establish one value of correlation between each variable of input and of output, in such a way that low values implicate in small influence of the input variable in the output variable whereas high values implicate in large influence.

The estimation of the total value for each input variable, explicit in the last column, is done by the summation of multiplications among values of correlation rate and the rate of importance, as shown in the Equation 1.

$$Total = \sum_{i=0}^{n} C_{ji} \times T_i \qquad (1)$$

Where:

j – input variable index
i – output variable index
C - correlation rate
T – rate of importance

The example of the estimation of the total value of the correlations, simulating the analysis of blasting process is presented in Figure 5. For the analysis of the results, consider that as bigger the total value, more the influence of the input variable in the quality of final product. In this case, scale of 0 to 5 for correlations between input and output variables was adopted.

Process Map - Hint: *all process map must contain, in some moment, the primary metric			
Input Variable (x)	**Type**	**Phase of the Process**	**Output Variable (Y)**
X_1	Variable is Controlled (C) or Not-controlled (l)	**Phase 1**	Y_1 Y_2
X_2			
X_3			
X_4			
X_5		**Phase 2**	Y_3 Y_4
X_6			
X_7		**Phase n**	Y_n
X_n			

Fig. 3. Model of Process Map
Source: Adapted from [36]

Rate of Importance			(1 to 10)	(1 to 10)	(1 to 10)		
Phase of the Process	Input Variable	Output Variable	Y_1	Y_2	Y_3	. . .	Total
Phase 1	X_1		Correlation $X_1 - Y_1$	Correlation $X_1 - Y_2$	Correlation $X_1 - Y_3$		
Phase 2	X_2		Correlation $X_2 - Y_1$	Correlation $X_2 - Y_2$	Correlation $X_2 - Y_3$		
Phase 3	X_3		Correlation $X_3 - Y_1$	Correlation $X_3 - Y_2$	Correlation $X_3 - Y_3$		
...	...						

Fig. 4. Filling the Matrix of Prioritization
Source: Elaborated by authors.

Rate of Importance			7	8	5	5	7	9	9	7	9	5	7	5	5	5	
Phase of the process	**Input Variable**	**Output Variable**	Parts with Roughness	Parts with Bubble	High Layer	Low Layer	Coloration	Parts with Peeling	Failure in the Zinc Deposit	Matt Parts	Parts with Stains	Parts with Oxidation	P arts with Burn	Parts with Reídues of Lard	Parts with Scratches	Parts with Purges	**Total**
Blasting	**Parts with Burr**		1	5	0	0	0	5	3	0	0	1	1	3	0	0	**146**
			1x7	**5x8**	**0x5**	**0x5**	**0x7**	**5x9**	**3x9**	**0x7**	**0x9**	**1x5**	**1x7**	**3x5**	**0x5**	**0x5**	**146**

Fig. 5. Estimation of the total value of Matrix of Prioritization

Besides to identify input variables that present large influence in the output variables, this must be prioritized in the improvement task, must establish an adequate measuring system, since this will serve to monitor the effects of the improvement during and after the implantation of solutions. For that, [32] suggest the identification of more representative indicators, besides to verify the reliability of measuring system, which involves apparatus as caliper rule, weighing machine, thermometers, and others. For the measurement by attribute, in which the product is analyzed as "approved" or "rejected", without presenting numerical values, operators that assess the product compound the measuring system. In this case, the way to evaluate measuring system is by the estimation of coincidence Kappa index. This index shows the coherence of obtained results among several operators and suppliers by themselves in repeated verifications, considering the set of parts previously selected and classified as good and bad.

To estimate the Kappa index between two operators named by A and B, initially must determine, among evaluated samples, how many were considered approved by both operators (X_{11}) and how many were rejected by them (X_{22}). Besides, is necessary to evaluate how many of samples were approved by the operator A (Y_a) and how many were rejected (Z_a). Same estimation must be done by operator B, obtaining, the Y_b and the Z_b, respectively. Next step consists to estimate observed portions, that consists in dividing each variable X_{11}, X_{22}, Y_a, Z_a, Y_b e Z_b by the total number of evaluated samples, generating respectively the variables O_{11}, O_{22}, OA_1, OA_2, OB_1 and OB_2. The values OB_1 and OB_2, for example are the results of the division of Y_b by the total of the sample. Aiming to consider approved or rejected parts by operators, then are estimated the expected proportions, denominated E_{ii}, in which i varies from 1 to 2, calculated using the Equation 2:

$$\boldsymbol{E_{ii} = OA_i \times OB_i} \tag{2}$$

Finally, the Kappa index is estimated using the Equation 3:

$$Kappa = \frac{(O_{11}+O_{22})-(E_{11}+E_{22})}{1-(E_{11}+E_{22})} \tag{3}$$

According to [27], are accepted values of Kappa index above 0.75. For results below this value, recommends the training of operators and the reassessment of the criteria of rejection of parts.

At the end of the final stage, determine the initial capacity of the process and the Sigma level in which is found. To determine the Sigma index, recommends the analysis of one sample of parts with enough quantity to explicit alterations of the process. Measurements, by attribute, must be classified as approved or rejected, following, must estimate de value of

DPMO, as shown previously. This value must be located in the Table 1, aiming to determine Sigma level of the actual process.

Analysis phase

In this phase, the objective is to identify problems resulting from the fabrication of a given product and the causes, based in the collected data in the previous phase. To help in these procedures, there are several auxiliary methods, however this work adopted the process of FMEA, which helps to identify possible failure mode in the fabrication process and its causes, explicating the critical failures which will demand corrective and preventive actions [9].

The complementary manual of the FMEA of the QS 9000 define this technique as a group of systemic activities, aiming to recognize and evaluate potential failure of the process and its effects, identify actions that can eliminate or reduce the probability of potential failure mode to occur and record the analysis of the process.

To this analysis, the process of FMEA utilizes the spread sheet shown in the Figure 6, which is filled, firstly with the stages of the process to be assessed, highlighting more critical inputs, identified previously. Following, started the analysis to identify potential failures of this process, detailing how this can occur failure and what effects will come with its occurrence. According to the effects, score the severity of the failure. Then, must be identified all possible causes of the failure, associating the level of occurrence of these causes. Afterwards, are considered two important items to control these causes: if there is any type of control that can act in the cause of the failure and if it can be detected in the line before it occur. After the definition of the three indexes related to severity, occurrence and detection, utilizing an adequate scale, these are multiplied, determining the number of Priority of Risk, called RPN (Risk Priority Number). The causes associated to high RPNs must be prioritized to take corrective or preventive actions [17]. One example of the table utilized for FMEA is presented in the Figure 6.

This phase results in the definition of critical problems, associated to causes that must be prioritized in the work for the improvement that follows, as these represent high risk for the process, consequently for the resulting product.

Improvement Implant Phase

In this phase, the team must do the improvement in the existing process, translating the statistical data in process data, acting over root causes [37]. According to [21] the objective of this phase is to remove the errors causes, tracking down present the performance within an acceptable limit.

According to [32] is in this phase that the work on definition, measurement, and analysis present the results. The authors list some factors that could hide the benefits of the Six Sigma project, as an example, the lack of creativity, the failure to examine solutions from the start to the, futile and random implantation, and an organizational resistance. Author [18] also pointed out that is important to maximize the benefits, taking an advantage, for example, solutions that can attend or improve other issues.

The main technique utilized in this phase is the DOE [2]. This technique has as an objective detail and plan the quantity of experiments to be done, such a way that the input variables be altered and its impacts over the response be assessed, allowing an identification of the best combination of variables [37]. One example of practical applicability of this method can be seen in [14]. Based in the results obtained with the aid of the DOE or other method, that aid in the identification of best combination of variable of one process, aiming to achieve the best possible result, perform the pilot test in small scale to identify difficulties and the feasibility of the chosen solution.

During the implantation of improvements, new measurements must be done, using initially selected performance indicators, aiming to confirm the reduction or elimination of the problem. If these measurements confirm the expected results, the improvements must be implanted in large scale, aiming to approach the level of quality 6 σ.

Failure Mode and Effects Analysis

FMEA

Product: ________ Level of Revision:_______

FMEA number:_______
Date of the FMEA: ______
Updated in:_______
Pilot: _____________

Definition Phase of the Process	Input of the Process (X`s)	Potential Failure		Severity	Potential Causes of Failures	Occurrence	Controles Atuais		Detection	NPR	Recommended Actions	Responsible	Deadline of Execution
		MODE	EFFECT				Prevention	Detection			Description		
In which phase of the process X arises	X`s previously prioritized	How this X can fail?	Which effect this failure?		What can have caused this failure?		Which modes of control for prevention of this failure?	Which modes of control for detection of this failure?			Which action recommended?	Who will be the responsible?	Which deadline for execution?

Fig. 6. Filling the spread sheet of FMEA

Control Phase

The closing phase of the DMAIC consists in identify means to keep the improvement [21]. Among resources adopted, in this phase highlights: control plans, control charts, and processes by error proofing [51]. The "control plan" is the formal document, represented by one spread sheet that pursuit guarantee that the process will operate within specified limits, minimizing the needs of new adjusts in the process [43]. The document must present all characteristics of the process, with dimensions and tolerances. Besides informs if the data regards to a critical characteristic, which form and frequency of the measurement for which action plan or containment must be taken, if the characteristic falls out of specification, including the responsible for this action.

The "control chart", also called "control graph", is a graphical record of data of one event throughout the time, in face of limits of control [38]. In general, one control graph is composed by three parallel lines, in which the central line represents an average characteristic value; the upper line represents the upper limit of control (ULC) and the lower line represents the lower limit of control (LLC) [48]. In the case of one or more points are found out of the limits of the specification, is understood that the process is "out of control". An example of "control chart" in which the process is controlled according to the values that are within the previously established limits is shown in Figure 7.

In this phase expect the "Approval of the Proprietor of the Process". The 6 σ project leader makes a presentation of results achieved and transfer the responsibility of control plan to the proprietor of fabrication process [43]. Finally, this is the last phase of the DMAIC method. Considering that this work aims to show the application of 6 σ in one small company, without the support of specialized consultants, the next item presents some considerations about the profile of company, in which can have an impact in demand for little modifications in the strategy of application new methodology, previously presented.

B. The size of the company

The criterion to define the size of company follows the characteristics of the country in which is located and the aims of the classification [19]. Among classification forms, can be mentioned the number of employees, net asset, annual invoice, and others [31].

According to [50], the small enterprises of the industrial sector are classified by the number of employees, which varies from 20 to 99.

The review made by [15] shows that the Brazilian SMEs have the following characteristics:

- Concentration of the decision taking in the hands of the manager (or entrepreneur) and the family administration type, that makes the quality of decisions be compromised, but allows decision process great agility;
- Decision taking with emphasis in short term, that make difficult the investment and the maintenance of programs with returns in medium and long terms;
- Employees with little career perspective, low qualification and little formal training, but in compensation, good insight of the processes, products and clients, due to a proper dimension of the enterprise;
- Little investment in technology and innovation;
- Restriction to niches of the market or subordinated to large clients when organized in chain.

As cited by [29], the SMEs possess, frequently sole proprietor or is the propriety of small group of persons. Commonly, are managed by the proprietor, in which becomes the center of decisions, besides the financial capital basically provided by him. By the analysis of such characteristics, it can be considered that the critical items to implant 6 σ are low qualified employees with few formal training, besides low potential for investment. In another hand, the power for a decision taking is centered that could facilitate, considering the support by the owner of the company and the agility in the decision process.

Due to the financial restrictions, when a small company operates with high rates of rework, it can reach the limit forcing to quit the business. If the small company wishes to improve the business, by adopting the strategy as the "6 σ" type, according [10], it is necessary alter some paradigms. For example; change the short term vision for profit to the long term, focus in the process and not only in product, understand that the training is the investment and not stipend, must change the reactive behavior to proactive, among others.

Chart 2 presents some suggested recommendations by references [4], [5], [20], considering the difficulties of the small enterprises and suggestions to implant 6 σ. It is important to highlight the importance of 6 σ for a small enterprise, considering that this contributes to eliminate defects and reworks in the production, impacting in the reductions of costs significantly, improve the process performance and the quality of the products.

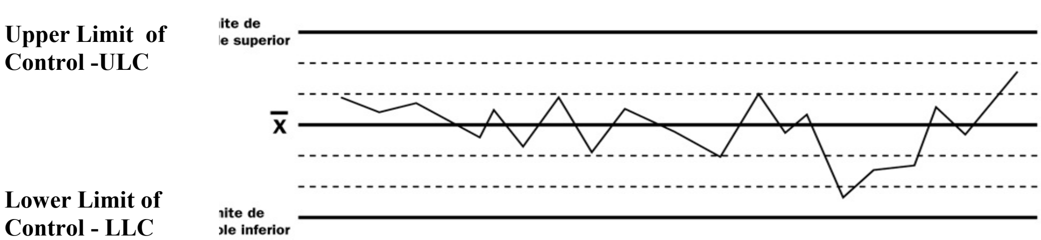

Fig. 7. Example of control chart (Elaborated by Authors).

CHART 2 – RECOMMENDATIONS FOR APPLICATION OF 6 σ N IN SMALL ENTERPRISE

Main Difficulties	Recommendations
Creation of an appropriate culture	- Training on quality - Commitment of the owner and his influence within the group.
Financial investment	- Wait the result of the application in one project to apply to other
Training of workers involved in the improvement of project	- Hire the external agents to coordinate the implantation of 6 σ - Invest in training of White Belts (40 h) - Utilize the academic knowledge / partnership with universities.

Taking an account the concepts and literature reviews presented, the next section details the strategy of application of 6 σ in small enterprise, showing the practical results obtained in industrial sector.

IV. APPLICATION OF THE 6 σ IN SMALL ENTERPRISE

The case chosen for the application of 6 σ, utilizing DMAIC method was a small enterprise with 60 employees, located in Curitiba, specialized in surface treatment of serial parts for automobile industries. Among treatments in the enterprise, depict the “zincifying process”, whose objective is to protect the surface of parts against corrosion. This process consists in initial cleaning of parts, with subsequent immersion in the tank with zinc, in which ions of the zinc are transferred to parts by electrolysis. The steps involved in the process to zincify can be seen in the flow shown in the Fig. 8.

The coming sessions present how the DMAIC was applied in this process.

A. Define Phase

The first phase of the project started with the definition of the team. The team was composed by 10 persons, including the company owner, the quality manager, production supervisor, 2 quality analysts, 3 production line operators, and one author of this article, who acted as the coach of the project. One of authors guided the application of 6 σ in the shop floor assessing partial and final records. Due to the actuation within the company, the members of the team were settled in the role compatibles as presented in the Chart 1. Following, the schedule of application and other details was defined to compose the Chart of Project.

Considering the experience of collaborators and the top manager, the evidence, is that the main problem of the company was the delay to deliver products to final client. In a quick assessment, the team concluded that the delay to deliver has as the main reason the high rate of rework that impacted to redo the surface treatment process, doing again all stages presented in the flowchart of the Figure 8. Based in the data of previous months, it can be seen that the rate of rework reached 36% of parts produced, that explicit the problem that this index represents to the company and to the client. As an initial goal of the project, the team suggested that the rate of rework reduced to10% of parts produced, considering that this profile of process has natural loss due to the large number of non-controllable variables.

So that, it was defined the Mission of the Project (Statement of the Goal) through 5W1H technique, defining that “the rework be reduced to minimum of 10% of parts produced, aiming to reduce delay to deliver, by the use of DMAIC approach between September and December of 2010”. After these definitions, the Chart of Project was detailed, as presented in the Chart 3.

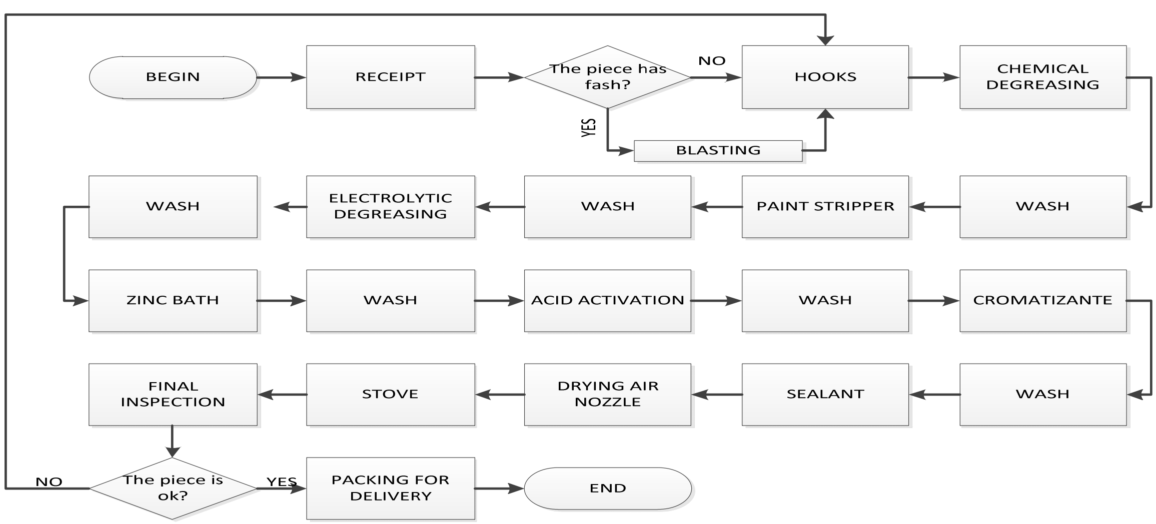

Fig. 8. Flow process to zincify
Source: Elaborated by authors

CHART 3 – CHART OF PROJECT

CHART OF PROJECT
Statement of the problem: Clients feel the prejudice by the delays in the delivery of products due the high rate of rework that reaches more than 30% of products. **Statement of the target**: Reduce the delays to deliver by the reduction of reworks to less than 10% of parts produced. **Guidelines of the team**: The team will meet once a week in the schedule to be defined in the meetings to discuss the results and new decisions. **Members of the team**: Company owner, quality manager, quality analyst 1, quality analyst 2, laboratory operator, production leader, final inspection operator, production supervisor and external consultants (authors of this paper). **Preliminary plan of project**: Forecasted schedules for the conclusion of each stage of the DMAIC: Define (15/Sep/2010), Measure (15/Oct/2010), Analyze (15/Nov/2010), Implant (15/Dec/2010), Control (30/Dec/2010).

Source: Elaborated by authors

CHART 4 – PROCESS MAP

Input Constraints	**Stages of the Process of Zincifying**	**Output Constraints** (Evaluation methods)
Parts with burr	Blasting	Parts free of burr
Pressure of blasting		
Time of blasting		
Quantity of parts in blasting		Visual analysis
Adequate hook for parts	Hooking	Parts hold by hooks
Condition of the hooks		Visual analysis
Parts with oil and grease	Chemical degreasing	Parts without oil and greases
Concentration and time of the alkaline solution		
Time of exchange of degreasing		Visual analysis
Parts with impurity in the welded zone		
Time of permanence of parts		
Parts with excess of degreasing solution	Washing	Parts without excess of solution
Parts with scale	Acid pickling	Parts without scale
Acid concentration		
Time of exchange of pickling		Visual analysis
Time of permanence of parts		
Parts: excess of pickling solution	Washing	Parts without excess of solution
Parts with micro scales	Electrolytic degreasing	Parts with deep cleaning
Degreasing concentration		
Time of exchange of degreasing		
Time of permanence of parts		Visual analysis
Current of the electrolytic degreasing		
Parts with excess of degreasing solution	Washing	Parts without excess of solution
Cleanning parts	Zinc bath	Parts zincified
Zinc concentration		
Soda concentration		
Addition of additives		Analisi of intraprocess layer
Current of the zinc do bath		
Time of permanence of parts		
Parts with excess of zinc bath	Washing	Parts without excess of solution
Parts zincified	Acid activation	Activated parts
Ph of the activated acid solution		
Time of exchange of activated acid solution		
Parts – excess of acid activation	Washing	Parts without excess of solution
Activated parts	Chromate	Parts chromate quenched
Chromate concentration		
Ph of the chromate solution		
Time of exchange of the chromate solution		
Iron concentration		Parts without stains
Time of permanence of parts		
Parts - excess of chromate	Washing	Parts without excess of solution
Parts chromate quenched	Seal layer	Parts sealed
Seal concentration		
Ph of the seal solution		
Wet parts	Air nozzle dryer	Moisture parts
Temperature of the oven	Oven	Dried parts
Finished parts	**Final Inspection**	**Parts according to specifications and other assessments**

Source: Elaborated by authors

B. Measure Phase

Aiming to understand better the zincifying process and identify more critical procedures, the 6 σ team built the Process Map, as shown in the Figure 3. The technique consists in detail how the parts come to each stage and which variables are involved as, for example, temperature, time, electric current, and others. The information is called as “input variables” and is described in the left side of each stage of the process. Following, detail the expected state of parts at the final stage of each process if there is any inspection in this stage. The information is called output variables and is described in the right side. In the mapping of the zincifying process, were identified 18 stages, in which the total of 48 inputs and 39 outputs, as partially shown in the Chart 4.

From the analysis of the Process Map, the team defined that the main variables of output to be considered in the Matrix of Prioritization is the output stage of the final inspection found, meaning that the possible defect that could be found in the parts after passing all stages of zincifying process.

Aiming to prioritize the disapproval criteria, the team attributes one Rate of Importance (RI) variable of 5 to 9 for each one of 14 defects identified in final inspection, as shown in the Table 2 and in the Figure 9. To determine the RI, it was utilized a Pareto´s Graph, filled with the number of occurrences of each problem, verified between March/2010 and August/2010 (See Fig. 9). From the graph generated, the team defined that following occurrences generate RIs: above 10% (RI 9); between 5% and 10% (RI 8); between 1% and 5% (RI 7); lower than 1% (RI 5). The data collected is shown in Table 2

The corresponding Pareto´s Graph from the Table 2 is shown in the Figure 9.

From the Pareto´s Graph, it is concluded that most frequent problem is the surge of stains in parts after zinc bath, followed the failure in the deposition of zinc and peeling of the layer, which received the score of the rate of importance 9 – (RI 9). The occurrence of bubble was the next failure that received RI 8. Following, presented the roughness, coloration, occurrence of burning and dull parts with RI 7. Among minor occurrences, presented an oxidation of parts,

TABLE 2 – DATA COLLECTED IN THE SURVEY

PROBLEMS	NUMBER OF OCCURRENCES	PERCENTILE	ACCUMULATED PERCENTILE
Stains	4,206	36.32	36.32
Failure in the zinc deposit	2,969	25.56	61.88
Peeling	1,765	14.38	76.25
Bubbles	980	8.46	84.72
Roughness	432	3.73	88.45
Coloration	428	3.70	92.14
Burn	338	2.92	95.06
Matt	290	2.50	97.56
Oxidation	98	0.85	98.41
Low Layer	96	0.83	99.24
Scratches	57	0.49	99.73
High Layer	19	0.16	99.90
Lard	8	0.07	99.97
Purges	4	0.03	100.00
Total	11,581	100	

Source: the authors

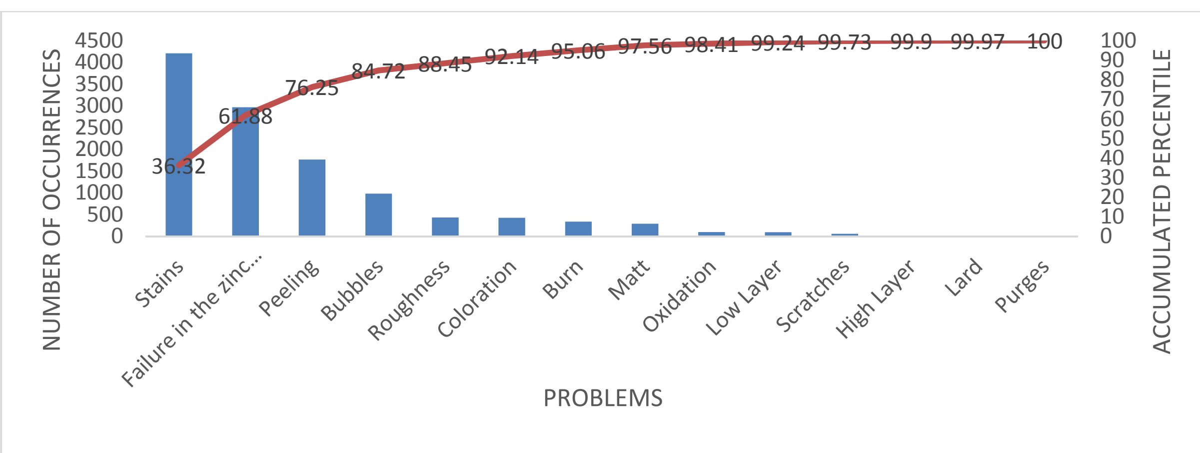

Fig. 9. Pareto´s Graph
Source: Elaborated by authors

scratches, parts with lard, purged, and problems of the layer of zinc in excess or in absence, that received RI 5 (See Table 2).

After prioritize the defects, it was necessary to understand in which stages of zincifying process presented major influence in the occurrence of these nonconformities. For that, started the filling of the "Prioritization Matrix", where the first column presents all input variables described in the Process Map and de second line presents all defects with respective rate of importance. To correlate the input variables with each defect, the team stipulated the values of correlation according to the following criteria: (0) None Correlation; (1) Low Correlation; (3) Medium Correlation, and (5) High Correlation (See Table 3). The total result in the last column of each line refers to the summation of the multiplication of the level of correlation of input with output and the rate of importance. It means, for the first line, the following estimation was performed: Summation (∑) = (1*7) + (5*8) + (0*5) + (0*5) + (0*7) + (5*9) + (3*9) + (0*7) + (0*9) + (1*5) + (1*7) + (3*5) + (0*5) + (0*5) = 146.

TABLE 3 – MATRIX OF PRIORITIZATION

Rate of Importance		7	8	5	5	7	9	9	7	9	5	7	5	5	5	
Input Variable	**Output variables**	**Parts - roughness**	**Parts with bubble**	**High layer**	**Low layer**	**Coloration**	**Parts - Peeling**	**Failure in zinc Deposit**	**Matt Parts**	**Parts - stains**	**Parts - oxidation**	**Parts - burn**	**Parts - lard**	**Parts – scratches**	**Parts - purged**	**Total**
Parts with burr		1	5	0	0	0	5	3	0	0	1	1	3	0	0	146
Pressure of blasting		3	3	0	0	0	3	3	3	1	0	0	0	0	0	129
Duration of blasting		0	3	0	0	0	1	1	0	0	0	0	0	0	0	42
Quantity of parts in blasting		0	3	0	0	0	3	1	0	0	0	0	0	0	0	60
Adequate hooks for parts		0	3	0	0	0	3	3	0	0	0	3	0	3	0	114
Condition of hooks		0	0	1	1	0	0	5	0	0	0	3	0	0	0	76
Parts with oil and grease		0	5	0	0	1	5	3	3	3	0	0	5	0	0	192
Concentration of the alkaline solution		0	5	0	0	0	3	3	0	0	0	0	5	0	0	119
Temperature of the alkaline solution		0	5	0	0	0	3	3	0	0	0	0	5	0	0	119
Time of exchange the degreasing		0	3	0	0	0	3	3	0	0	0	0	3	0	0	93
Parts with impurity in the welded zone		1	5	1	5	3	5	5	3	1	1	5	5	5	5	333
Time of permanence of part		0	5	0	0	0	5	3	0	0	0	0	5	0	0	137
Parts with excess of chemical degreasing		0	5	0	0	0	5	3	0	0	0	0	5	0	0	137
Parts with scales		5	3	0	0	0	5	1	0	0	0	0	0	0	0	113
Concentration of acids		0	3	0	0	0	3	1	0	0	0	0	0	0	0	60
Time of exchange of pickling		3	5	0	0	0	3	0	0	0	0	0	0	0	0	88
Time of permanence of parts		0	5	0	0	0	5	1	0	0	0	0	0	0	0	94
Pats with excess of pickling acid		1	5	0	0	0	3	1	0	0	3	0	0	0	0	98
Parts with micro scales		0	3	0	0	0	3	1	0	0	0	0	0	0	0	60
Time of exchange of degreasing		0	3	0	0	0	1	0	0	0	1	1	0	0	0	45
Time of permanence of part		1	3	0	0	0	3	0	1	1	0	3	0	0	0	95
Current of electrolytic degreasing		0	3	0	0	0	3	1	0	0	0	3	0	0	0	81
Parts with excess of electrolytic degreasing		1	3	0	0	0	3	0	0	0	0	0	0	0	0	58
Clean parts		5	5	0	0	3	5	5	3	3	1	3	3	0	3	290
Zinc concentration		0	3	5	5	0	5	5	3	3	0	5	0	0	0	247
Soda concentration		1	0	0	0	0	1	3	3	3	0	0	0	0	0	91
Addition of additives		0	3	5	5	3	5	5	5	5	0	3	0	0	1	291
Current of the zinc bath		3	5	5	5	1	5	5	1	0	0	5	0	0	0	250
Time of permanence of part		0	5	5	5	0	5	5	3	0	0	5	5	5	5	311
Parts with excess of zinc bath		1	0	0	0	3	0	0	0	5	1	0	0	0	1	83
Parts zincifyed		0	0	0	0	5	0	0	5	5	3	0	0	0	0	130
pH homogenizer of solution of acid activation		0	0	0	0	5	0	0	3	5	0	0	0	0	0	101
Time of exchange solution of acid activation		0	0	0	0	5	0	0	3	3	0	0	0	0	0	83
Parts with excess of acid activation		0	0	0	0	3	0	0	1	3	1	0	0	0	1	65
Activated parts		0	0	0	0	5	0	0	0	5	1	0	0	0	0	85
Chromate concentration		0	0	0	0	5	0	0	5	5	3	0	0	0	3	145
pH of the chromate solution		0	0	0	0	5	0	0	0	5	0	0	0	0	0	80
Time of exchange of chromate solution		0	0	0	0	3	0	0	0	5	3	0	0	0	3	96
Iron concentration		0	0	0	0	3	0	0	0	1	5	0	0	0	5	80
Time of permanence of part		0	0	0	0	5	0	0	1	5	3	0	0	0	0	102
Parts with excess of chromate quenching		0	0	0	0	3	0	0	0	3	1	0	0	0	3	68
Parts chromate quenched		0	0	0	0	3	0	0	0	5	5	0	0	0	0	91
Sealant concentration		0	0	0	0	5	0	0	0	3	5	0	0	0	5	112
pH of the sealant solution		0	0	0	0	3	0	0	0	3	3	0	0	0	0	63
Compressor functioning		0	0	0	0	3	0	0	0	5	5	0	0	0	0	91
Temperature of the stove		0	0	0	0	3	3	0	0	5	3	3	0	0	3	144

The interpretation of results obtained in last column, related to the total of each input variable, means that the larger values must have priority input for the study, as have strong correlation with some defects that occur with frequency in the process. So that, after the elaboration of the prioritization matrix and the estimation of total value for each input variable, the matrix was classified in decreasing order of total value, determining input variables and process stages to be prioritized.

The team defined that the input variables that presented total values above 145 must be prioritized, restricted the improvement actions to eight main input variables, presented in the Table 4.

Aiming to guarantee reliable measurements, at the beginning of the 6 σ project, two operators in charge of final inspection assessed the products considering the measurement by attributes. For that, 20 parts were utilized, previously analyzed by the quality manager, in which each part was analyzed three times by quality inspectors. Data obtained by inspectors were compared each other and with the standard stipulated, generating three Kappa index, as shown in the Figure 10.

As three values were above 0.75, understands that the measuring system was approved, as explained previously, as can be seen in the Figure 11. Details about the estimation of this index can be found in [38] MSA 4th Edition (2010).

TABLE 4 – MAIN VARIABLES OF INPUT OF THE ZINCIFYING PROCESS

Input variables	Total obtained in the Prioritization Matrix
1. Parts with impurity in the welded zones	333
2. Time of permanence of part in the zinc bath	311
3. Addition of additives in the zinc bath	291
4. Clean parts	290
5. Current of the zinc bath	250
6. Zinc concentration	247
7. Parts with oil and grease	192
8. Parts with burr	146

STARTING VALUES				OBSERVED PROPORTIONS				EXPECTED PROPORTION		
	OPERATOR 2				OPERATOR 2				OPERATOR 2	
Operator 1	OK	NO OK	TOTAL	Operator 1	OK	NO OK	TOTAL	Operator 1	OK	NO OK
OK	42	3	45	OK	0. 67741935	0.0483871	0.72580645	OK	0.51508845	0.210718
NO OK	2	15	17	NO OK	0.03225806	0.24193548	0.27419355	NO OK	0.19458897	0.07960458
TOTAL	44	18	62	TOTAL	0.70967742	0.29032258	1			
	STANDARD				STANDARD				STANDARD	
Operator 1	OK	NO OK	TOTAL	Operator 1	OK	NO OK	TOTAL	Operator 1	OK	NO OK
OK	42	0	42	OK	0.7	0	0.7	OK	0.525	0.175
NO OK	3	15	18	NO OK	0.05	0.25	0.3	NO OK	0.225	0.075
TOTAL	45	15	60	TOTAL	0.75	0.25	1			
	STANDARD				STANDARD				STANDARD	
Operator 2	OK	NO OK	TOTAL	Operator 2	OK	NO OK	TOTAL	Operator 1	OK	NO OK
OK	42	0	42	OK	0.7	0	0.7	OK	0.53666667	0.16333333
NO OK	4	14	18	NO OK	0.06666667	0.23333333	0.3	NO OK	0.23	0.07
TOTAL	46	14	60	TOTAL	0.76666667	0.23333333	1			

Fig.10. Matrices of Proportions to estimate Kappa index

Kappa index between operators A and B
KAPPA A-B = $\frac{(0.67742+0.24193)-(0.51509+0.07960)}{1-(0.51509+0.07960)} = 0.801$
Kappa index between operator A and Standard
KAPPA A = $\frac{(0.7+0.25)-(0.525+0.075)}{1-(0.525+0.075)} = 0.875$
Kappa index between operator B and Standard
KAPPA B = $\frac{(0.7+0.233333)-(0.53667+0.07)}{1-(0.53667+0.07)} = 0.83$

Fig. 11. Kappa index of the final inspection

TABLE 5 - SIGMA LEVEL IN THE BEGINNING OF THE PROJECT

Data from Manual Line					
Mo/2010	Qty Produced	Qty Rejected	Percentile	**DPMO**	**Sigma level**
March	5,029	921	18.3	**183.138**	**3**
April	9,259	1,360	14.7	**146.884**	**3**
May	3,404	1,229	36.1	**361.046**	**2**
June	11,966	3,015	25.2	**251.964**	**2**
July	8,821	1,757	19.9	**199.184**	**2**
August	5,123	1,739	33.9	**339.450**	**2**
Average	7,267	1,670.16667	22.9828907	**229.829**	**2**

Aiming to estimate the level of initial Sigma of the project, average values were utilized, regarding to the number of parts rejected in the final inspection, between the months of March/2010 to August/2010, considering the values DPMO (Defects per Million of Opportunities) shown in the Table 1. In the Table 5 are presented the DPMO indicators of the months of March, April, May, June, July, and August of 2010, the corresponding Sigma levels and the average Sigma these months, considering the integer value without decimal figure.

As shown in the Table 5, the historical of zincifying process presents, in the beginning of September, one level Sigma as an average results this process. According to the Table 1, the level 2 Sigma means to compromise up to 25% of sales in costs due to the lack of quality. In the case of the process studied, the costs due to the lack of quality were driven by the rework of parts rejected in the final inspection.

After the analysis of the stages of the process, the input and the output of each sub-process also prioritize main input variables and the next phase of DMAIC had an objective to analyze what can happen in each one the prioritized input that compromises the final product.

C. Analize phase

To analyze the failures and its causes identified in the process, it relied on analysis of the 8 input variables from the results of the Matrix of Prioritization, as shown in the Table 4. These variables were inserted in the spread sheet of the FMEA of process, aiming to explore possible causes of occurrences. Aiming to present how it was analyzed, the two variables that presented major index of risk (NPR) are presented in the Charts 5, 6 and 7. Afterwards, for each mode of failure, the team described the effects caused by these failures, if it occur again, described in the column “Effects of the Failure”, stipulate the values between 0 to 10 for the severity of these effects.

Afterwards, the team assessed possible causes that conducted to these failures, unleashing the filling of the column “Potential Cause of the Failure”, scoring from 0 to 10 regarding to the probability of occurrence. Following, the team gave the sequence of filling of the FMEA over actual control of prevention and detection, scoring from 0 to 10 about the ability of detection of these controls. This information are shown in the Chart 6.

CHART 5 – PROCESSES OF FMEA: POTENTIAL FAILURES AND DEGREE OF SEVERITY

Definition of process steps	**Input of process**	**Potential Failure**		**Severity**
		FAILURE MODE	**FAILURE EFFECTS**	
Chemical cleaning	Parts with impurities	Parts with impurities in the welded zone	Roughness, bubble, coloration, peeling, failure in the deposit, dull parts, stains, oxidation, burn, lard, purges.	8
Zinc bath	Cleaned parts	Parts with oils and greases	Roughness, bubble, coloration, peeling, failure in the deposit, dull parts, stains, oxidation, burn, lard, purged.	8

CHART 6 – POTENTIAL CAUSES OF FAILURE AND ACTUAL CONTROLS

Failure mode	**Potential causes of failure**	**Occurrence**	**Actual Controls**		**Detection**
			Prevention	**Detection**	
Parts with impurity in the welded zones	The processes utilized for the cleaning of parts are not efficient in the welded zones	8	Work Instruction	Visual Intra-process	8
Parts with oils and greases	1. The temperature of the concentration of the degreasing is not respected, requiring to leave more time than specified	6	Work Instruction	Visual Intra-process	8
	2. The concentration of the degreasing is not enough to do the cleaning	6		Laboratory analysis (dairy)	8
	3. The temperature of the degreasing is not enough to do cleaning	6		Laboratory analysis (dairy)	8

CHART 7 – NPR VALUE AND RECOMMENDED ACTIONS

Failure mode	Severity	Occurrence	Detection	NPR	Recommended Actions Description	Responsible	Execution due
Parts with impurity in the welded zone	8	8	8	512	Check, by the DOE, if deviation occur the process for utilization of hot hydrochloric acid after chemical degreasing solve the problem	Production supervisor	15/Nov/10
Parts with oils and greases	8	6	8	384	Determine the temperature / concentration of the degreasing time to 40 minutes be enough	Six Sigma team	30/Jan/11
	8	6	8	384	DOE to check ideal concentration	Trainer / Production supervisor	15/Nov/10
	8	6	8	384	DOE to check ideal temperature	Trainer / Production supervisor	15/Nov/10

Finally, the team estimated the risk index (NPR) by multiplying values of Severity, Occurrence, and Detection. After prioritized the failure modes, were proposed some actions, associated to the responsible, including the date for execution. This information is shown in the Chart 7.

Considering the analysis of 8 variables of input, results of the Prioritization Matrix, only explicit failures previously presented high rate of risk (NPR) requiring the tests in the production line to assess the parameter more indicated to reduce the failures occurrence. So that, only these failures is explicit in this paper. In the full report, the NPRs vary from 64 to 512.

In the first case, where the stages of chemical and electrolytic degreasing are not enough to remove the impurities located in the welded zones, the team decided to perform the tests to assert the efficiency of the cleaning done with hot hydrochloric acid, with concentration of 40%. To perform the tests one modification was done in the usual process, in which after the chemical degreasing, the parts will be immersed in a tank with hydrochloric acid.

The second and third of prioritized modes of failure were related to the temperature and concentration of the chemical degreasing. The laboratory operator approved the production hence the concentration of the bath is in the range of 60 g/l and 80 g/l, with temperatures between 60°C and 80°C. Aiming to determine ideal conditions of temperature and concentration of the chemical degreasing bath, the team decided that the best action will be to do the DOE together with modification in the process, and evaluate which will be the situation that presents lower rate of rejected parts.

Other failure modes, treated in the FMEA, had as main actions; the training of the employees about the importance of the quality in the process, review of maintenance plans of apparatus, implantation of assessment in the course of the process and the increase in the frequency of laboratory analysis.

D. Improvement Implantation Phase

Based in the failure modes prioritized in the FMEA and in three main actions to be implanted, the team defined the values that will be tested with the DOE:

- X1: Temperature of degreasing: 60, 70, and 80°C.
- X2: Concentration of degreasing: 60, 70, and 80 g/l.
- X3: Utilization of hot hydrochloric acid, with or without altering the usual process.

The values of temperature and concentration were considered an acceptable limit for the laboratory analysis for approval. Aiming to test the efficacy of the use of hot hydrochloric acid, all combinations were performed, with and without use of acid. To verify the efficacy of all actions taken it was defined as performance indicator the index of parts rejected, expressed in percentile. So, it was defined as best situation that presents less rework index in the period.

Table 6 presents, for each experiment, the input variables utilized, and as outputs, the following variables: the number of parts produced in the specific test condition, the quantity of parts approved, the quantity of parts rejected, and the index of rework (ratio between parts rejected and parts produced).The 18 tests performed were sufficient to simulate all combinations between variables described previously.

Initially, it can be seen that the experiments 3, 9, 11, 15 and 17 present rework indexes lower than 10%, according to the aims of the project. In more detailed analysis, it is possible to observe that the rejection indexes much lower for any temperatures, were obtained using the concentration of 70 g/l of degreasing. Besides, in all conditions, the use of hydrochloric acid reduced significantly the rework index. Fixing the concentration in 70 g/l and the use of the modification in the process, described previously, observe that as big as the temperature of the bath, smaller the index of rework, reaching 4.3% for the condition of the maximum temperature, within 80°C.

Aiming to validate the results obtained, the team decided to do, by the period of one month, confirmatory testing from the best condition obtained by the DOE: temperature of 80°C; concentration of 70 g/l, modifying the process with the use of hydrochloric acid. The Table 7 shows the results these tests, confirming the results obtained with DOE.

TABLE 6 – RESULTS OF THE DESIGN OF EXPERIMENTS

Inputs				Outputs			
N.	Temperature of the Degreasing	Concentration of the Degreasing	Utilize Acid?	Rework Index			
				Produced	Approved	Rejected	%
01	60	60	YES	243	215	28	11.5
02	60	60	NO	178	142	36	20.2
03	**60**	**70**	**YES**	**315**	**287**	**28**	**8.9**
04	60	70	NO	246	205	41	16.7
05	60	80	YES	254	227	27	10.6
06	60	80	NO	213	175	38	17.8
07	70	60	YES	505	448	57	11.3
08	70	60	NO	393	321	72	18.3
09	**70**	**70**	**YES**	**398**	**370**	**28**	**7.0**
10	70	70	NO	330	284	46	13.9
11	**70**	**80**	**YES**	**297**	**268**	**29**	**9.8**
12	70	80	NO	325	272	53	16.3
13	80	60	YES	230	205	25	10.9
14	80	60	NO	212	183	29	13.7
15	**80**	**70**	**YES**	**322**	**308**	**14**	**4.3**
16	80	70	NO	364	325	39	10.7
17	**80**	**80**	**YES**	**300**	**273**	**27**	**9.0**
18	80	80	NO	220	189	31	14.1

Source: Elaborated by authors

TABLE 7 – CONFIRMATION OF RESULTS OBTAINED WITH DOE

Date	Produced	Rejected	%	DPMO	Sigma level
03/jan/11	123	6	4.9	48,780	3
04/jan/11	300	12	4.0	40,000	3
05/jan/11	287	6	2.1	20,906	3
06/jan/11	182	6	3.3	32,967	3
07/jan/11	170	11	6.5	64,706	3
10/jan/11	215	8	3.7	37,209	3
11/jan/11	97	2	2.1	20,619	3
12/jan/11	147	6	4.1	40,816	3
13/jan/11	123	6	4.9	48,780	3
14/jan/11	177	11	6.2	62,147	3
15/jan/11	419	10	2.4	23,866	3
16/jan/11	287	6	2.1	20,906	3
17/jan/11	124	4	3.2	32,258	3
18/jan/11	312	14	4.5	44,872	3
19/jan/11	235	14	6.0	59,574	3
20/jan/11	221	8	3.6	36,199	3
21/jan/11	298	10	3.4	33,557	3
24/jan/11	243	12	4.9	49,383	3
25/jan/11	175	10	5.7	57,143	3
26/jan/11	134	8	6.0	59,701	3
Average Sigma					**3**

Source: Elaborated by authors

As presented, the aims of the project 6 σ in this small company could be concluded, because in the 20 tests the rework indexes do not exceeded the limit of 10%. Along with the more critical process of the company, by the amount of rework and delays, succeeded to evolve from the Level Sigma level 2, to Sigma level 3, impacting in significant economy for the company, without the necessity of large investments.

E. Control phase

In the last phase of DMAIC, the 6 σ team elaborated the Control Plan to guarantee that, after the conclusion of project, the guarantors can control the pertinent variables with necessary frequency, considering the actions to be taken, in the case of some parameters fall out of specified. Among control approached in this Plan, the dairy monitor of the concentration and temperature of the degreasing are included, with the values stipulated by DOE, and the control of the time of the bath. Besides the Control Plan, the Control Chart, it has been allocated to the production line, dairy, one quality analyst who updates the data with percentile of rework of the production. The Control chart with the data of January of 2011, when tests were performed to confirm the data previously obtained is shown in the Figure 12.

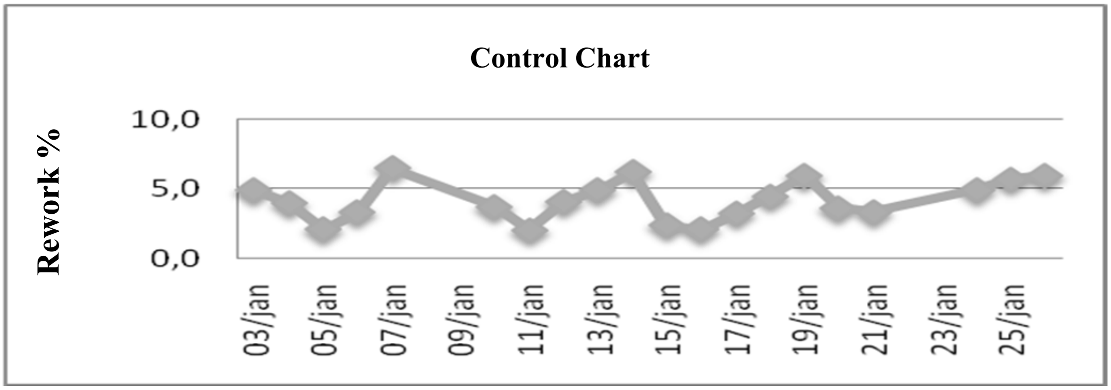

Fig. 12. Control chart

At the end of project has been noticed that, despite the team has stipulated as initial goal, to improve the zincifying process to have the maximum of 10% of rejection of final parts, after this work obtained the maximum of 6.5% of rejection until the day 01/07/11. The company understands that the levels of rejection lower than 10% are acceptable due to the instability of the chemical process. The monthly average of January of 2011 was 4% of rejection, whereas before the application of 6 σ, between March and August of 2010, the rejection index varied from 14.7% to 36.1%. It means, this application of 6 σ contributed to the company, getting by the initial goal.

V. FINAL CONSIDERATIONS

The application of the 6 σ in the SMEs is an emergent theme among academics in recent years, considering that this methodology was created originally for large companies. Yet there are few records of success of the 6 σ in profile of company, considering its limitations related to financial and human resources. Nevertheless, the profile of these companies presents contributive factors for the application of the 6 σ as, an example, the agility in the decision process, the support and commitment of top managers. So that, this article shows the practical application of the 6 σ by means of DMAIC method in small company that makes surface treatment by zincifying, to ascertain that this method can cause the positive impact. In this practical case, only few resources recommended in the application of the 6 σ were used, aiming to simplify and reduce the costs of procedures. Among them are: the built up of the 6 σ team, the definition of the more critical process, the elaboration of the project chart, the definition of the mission, the mapping of the process, the prioritization of variables using the Prioritization Matrix, the prioritization of the causes and actions of improvement with the use of the FMEA process, the performing of tests with the DOE and the elaboration of the Plan and Control Charts.

The analysis showed that the main causes of problems are related to the temperature and the concentration of chemical degreasing, that were not clearly defined nor the stages of cleaning not been enough to remove the impurity in the welded zone. So, it was performed 20 laboratory tests, aiming to determine the best conditions of temperature and concentration, besides to validate the efficacy of alteration in the initial process, which include more than one stage of cleaning. From the these tests, was possible to determine that the better performance of the process occurred with the temperature of the degreasing of 80°C and concentration of 70 g/l, considering the alteration of the usual process. It was evidenced that the application of the 6 σ in this small company was viable and beneficial, improving significantly the performance of the process delimited for the study; after all, the average reduction of the rework index reduced from 23% to 4%. Also qualitative gain was noticed as knowledge transfer to members of the team about the techniques of quality and the establishment of the culture to monitor and reduce defects through the measurement and control.

Among main obstacles found during the application of the methodology, can be cited the difficulty to gather 6 σ team in the established schedule, due to the activities exerted by them within the company. Also had some restrictions about the actions on low cost, respecting the low resources presented in typically small company. For the future work, suggests the application of 6 σ methodology in micro company, aiming to ascertain its viability and efficacy.

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