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Six Sigma in SMES with low production volumes. A successful experience in aeronautics.

Seis Sigma en PYMES con bajo volumen de producción. Una experiencia de éxito en aeronáutica.

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1. INTRODUCTION

In the current challenging economic environment, which requires a reduction in production costs while maintaining high levels of quality and reducing delivery times, the use of methodologies for the improvement of production and/or organisational processes is a very interesting proposition for any sector.

Six Sigma is considered to be one of the most powerful improvement strategies currently available to companies. Many large organisations in a wide range of different sectors have already adopted this strategy or have its adoption on their agenda (Kumar et al., 2008). It was conceived by Motorola in the 1980s with the aim of reducing variability and waste in very repetitive processes with high production volumes, through a systematic improvement methodology based on statistical techniques and tools.

Although Six Sigma has been exploited by many world class organisations, there has been relatively little documented evidence of its implementation in SMEs (Antony et al., 2008) although more examples have been found in a range of different sectors more recently (Paslawski, 2013; McAdam et al., 2014; Sharma & Sharma, 2014). However, these businesses play a key role in the economies of all countries. Therefore, it is a matter of interest to know the contexts in which Six Sigma can be applied, the best way for it to be implemented, and the main factors that lead to its success or failure.

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EXECUTIVE SUMMARY

Six Sigma is currently one of the most powerful tools that exists for quality improvement. Designed for highly repetitive and high volume production manufacturing processes, it has been adopted by leading large organisations in many different sectors all around the world. Our goal is to study its applicability to SMEs with low production volumes and identify key success factors and obstacles to its implementation. The methodology followed is Action Research in an SME in the aeronautics sector using the DMAIC improvement cycle applied to a specific Six Sigma project. The results confirm Six Sigma's applicability and suggest that success depends on key factors, such as the team's commitment, the availability of resources and prior learning.

RESUMEN DEL ARTÍCULO

Seis Sigma es actualmente una de las herramientas más potentes para la mejora de la calidad. Concebida para procesos productivos muy repetitivos y de gran volumen de producción, ha sido adoptada por las principales grandes organizaciones de todo el mundo en muchos sectores. Nuestro objetivo es estudiar su aplicabilidad en pymes, con bajos volúmenes de producción, e identificar los principales factores de éxito y obstáculos para su implementación. Se ha empleado la metodología "investigación en acción" en una pyme del sector aeronáutico, aplicando el ciclo de mejora DMAIC a un proyecto Seis Sigma concreto. Los resultados confirman su aplicabilidad y sugieren que el éxito depende de factores claves como el compromiso del equipo, la disponibilidad de recursos y la formación previa.

Implementing Six Sigma in SMEs is a challenge because their size, production volumes, levels of worker training and resources are all much smaller than in the case of large companies. In particular, the production processes of these companies often do not present the degree of repeatability for which Six Sigma has been created, either because of lower production volumes, greater product customisation, continuous changes in the product, or other factors.

The aeronautics sector is especially interesting for the study of continuous improvement methodologies such as Six Sigma. This is a highly competitive industry, where the priority is to ensure safety and airworthiness. Due to their operating conditions, aeronautics products are subject to very high quality, reliability and sustainability[2] standards. Therefore, the use of continuous improvement methodologies to enhance internal quality levels becomes virtually indispensable.

Six Sigma is considered to be one of the most powerful improvement strategies currently available to companies.

In recent years, there have been many incursions in this sector with Lean Production and they have finally started to achieve positive results internally (Crute et al., 2003; Mathaisel, 2005; Bhuiyan et al., 2006; Prida & Grijalvo, 2011; Martínez-Jurado & Moyano-Fuentes, 2014) and, to a more modest degree, externally with regard to achieving a more efficient supply chain (Sacristán-Díaz et al., 2012; Alfalla-Luque et al., 2013). The same is not true of Six Sigma, whose implementation has been scarce. One study of aeronautics companies (Zimmerman & Weiss, 2005) followed Six Sigma improvement programmes and shows that the outcomes were totally unsatisfactory in a non-negligible percentage (over 50%). Other studies for different sectors show similar results (e.g., Feng & Manuel, 2007). In most cases, it appears that the absence of a practical model for achieving the targets may doom the Six Sigma improvement project to utter failure. This last point was a decisive incentive to conduct this study of a Six Sigma project implementation at an SME in the aeronautics sector. Therefore, the objective of this paper is to study the applicability of Six Sigma in this context and to identify the main success factors and obstacles to its implementation in order to provide relevant implications and recommendations for practitioners.

The methodological approach followed is Action Research (AR) in order to produce research that, while contributing to theory, is of special value for practitioners, (Westbrook, 1995). To this end, and taking advantage of the Six Sigma training of one of the authors, it was proposed to the company that it could use this methodology to address some of the problems in its production area. The co-author worked for three months on the Six Sigma project at the firm being analysed. This enabled a close detailed study of the system, interaction with company members, and learning through the practical implementation of the activity (Coughlan & Coghlan, 2002).

KEY WORDS
Six Sigma; DMAIC; Quality; Aeronautics; Action Research.

PALABRAS CLAVE
Seis Sigma; DMAIC; Calidad; Aeronáutica; Investigación en Acción.

2. SIX SIGMA PROJECTS IMPLEMENTATION: KEY FACTORS AND OBSTACLES

The maximisation of financial performance that is typical of any business organisation, and the way to achieve it (by reducing waste and increasing customer satisfaction) are two key aspects usually combined in the definition of Six Sigma (Harry & Schroeder, 2000; Linderman et al., 2003; Kwak & Anbari, 2006). Thus, Six Sigma is considered to be (a) a business strategy used to improve financial performance and the effectiveness and efficiency of all operations with the primary objective of satisfying customer needs, as well as (b) a statistical tool which pursues defect rates of 3.4 units per million (equivalent to a quality level of 99.9997%).

Six Sigma makes use of many tools yet most of them are not original or specific to its methodology. For example, statistical tools such as EDA (exploratory data analysis), SPC (statistical process control), ANOVA (analysis of variance) and DOE (design of experiments), and non-statistics tools, such as FMEA (Failure mode and effects analysis), QFD (Quality Function Deployment) and Poka Yoke -all available to companies long before Six Sigma appeared- are used. However, as in other improvement approaches, Six Sigma requires quality to be measured objectively and provides a measurement metric for this that went on to give the name to the methodology (Linderman et al., 2003).

The Sigma (σ) variable represents the parameter that measures the variability of a statistical distribution, that is, its standard deviation. If the result of a process is a function that follows a normal probability distribution (most processes fit into the bell curve) and the tolerance range is equal to 12σ, which means six standard deviations each side of the nominal value, then the defect rate of a centred process would be 0.002 ppm (parts per million, which refers to the ratio between the number of defective parts to one million parts that would form the analysed sample). In this case, the process is said to have a 6σ quality level.

However, processes do not remain stable with an average fixed at the nominal value. If the nominal value is moved 1.5σ to either side, the defect rate would increase by up to 3.4 ppm. Therefore, the goal of Six Sigma is to achieve defect rates of 3.4 units per million opportunities (dpmo) for a defect to be able to appear in the sample. Given the nature of its measurement metric, it is not unusual for traditional Six Sigma techniques to be adjudged severely limited in highly changeable production contexts characterized by small batch productions and customized, or even one-of-a-kind products, as well as in-line product inspections (Colledani et al., 2014), which are all features that, to a greater or lesser extent, are present in most SME processes, and particularly in the aeronautics sector.

Regarding SMEs, a pilot survey in UK manufacturing firms showed that SMEs are not aware of Six Sigma and do not have the resources to implement Six Sigma projects (Antony et al., 2008). In addition, the low implementation of Six Sigma in the aeronautics industry, perhaps due to some of the special features of the sector mentioned above (low production volume, long production time, etc.), means that its implementation in aeronautics SMEs poses an even more difficult challenge, but a challenge that should be faced, considering the huge rewards that it can bring.

Studies reporting on Six Sigma implementation essentially emphasise the same obstacles and the same key factors that underpin its effectiveness, and these can be found in **Table 1**. Most point to management commitment, education and training, cultural change, and the link to business strategy being the most critical success factors in Six Sigma implementation. As for obstacles, some studies have investigated the reasons for not implementing Six Sigma, among which lack of awareness, no perceived benefits and insufficient resources stand out. Other studies have focused on factors that may lead to its failure, finding that the lack of resources (financial, human and time), lack of leadership, lack of training and internal resistance are among the most important. As with many of the improvement methodologies that organisations use to enhance the performance of their processes, Six Sigma often involves deep, mainly structural changes that sometimes produce rejection from workers. Six Sigma further aggravates these potential setbacks, since its success depends largely on the training that workers receive and, therefore, on a profound cultural change that enables the methodology to be assimilated with sufficient efficiency.

Table 1. **Implementation of Six Sigma Projects: Key factors for success and main obstacles**

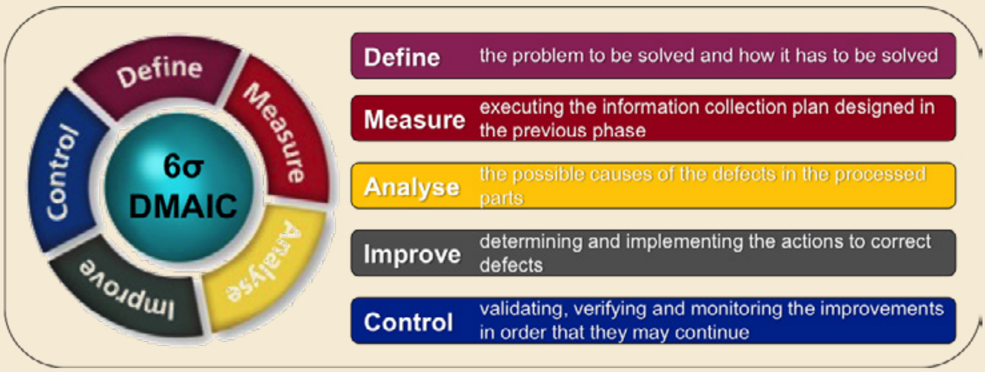
KEY FACTORS FOR SUCCESS	MAIN OBSTACLES
1. Management involvement and commitment 2. Cultural change 3. Organisation infrastructure 4. Training 5. Project management skills 6. Project prioritisation and selection 7. Understanding Six Sigma methodology, tools and techniques 8. Linking Six Sigma to business strategy 9. Linking Six Sigma to the customer, customer focus 10. Linking Six Sigma to employees 11. Linking Six Sigma to suppliers 12. Attaching the success to financial benefits 13. Organisational understanding of work processes 14. Clear performance metrics 15. Include all employees and all aspects of business appropriately	1. Not aware of Six Sigma 2. No perceived benefits 3. Existing Quality System is sufficient 4. Not required by customers 5. Lack of resources (this includes financial resources, human resources, time, etc.) 6. Lack of leadership 7. Poor training and coaching 8. Internal resistance (especially political resistance and technical resistance) 9. Poor project selection (lack of methodology, scope too large, unimportant or fuzzy objectives, and poor process performance metrics) 10. Lack of tangible results 11. Team too large

Source: Based on Antony & Banuelas (2002), Johnson & Swisher (2003), Antony et al. (2005), Kwak & Anbari (2006), Antony et al. (2008), Chakrabarty & Tan (2007), Brun (2011), and Näslund (2013

From the above discussion it can be deduced that SMEs encounter greater difficulties in the implementation of Six Sigma than larger firms, and it is easy to understand why its use is much less widespread. Lack of knowledge of its existence, lack of financial, human and time resources, and low employee training levels are some of the main obstacles. This is coupled with a lower volume of production that makes it difficult to use Six Sigma metrics and achieve its ultimate goal. It could be said that Six Sigma 'is too big' for most SMEs.

One important characteristic that defines Six Sigma is the use of a structured method (Schroeder et al., 2008). Six Sigma Projects usually apply the DMAIC (Define, Measure, Analyse, Improve, Control) cycle (Thomas et al, 2009) for process improvement. The route that this process has to follow is shown in **Figure 1**.

Figure 1. **The DMAIC Cycle in Six Sigma Projects**



This similarity to the Shewhart and Deming PDCA improvement cycle leads to what has been previously stated about Six Sigma making few contributions of its own. Therefore, its greatest merit lies in knowing how to structure each of these steps systematically, providing Six Sigma Project managers with statistical and non-statistical tools to enable the inputs and outputs to be better identified in each phase. The results and discussion will be presented in Section 4 following these five stages.

3. COMBINING ACADEMIC RESEARCH AND PRACTICE DEVELOPMENT THROUGH ACTION RESEARCH

Action Research (AR) is the methodological approach followed. As previously mentioned, this approach produces research that, while making contributions to theory, is of special value for practitioners (Westbrook, 1995). According to Alfaro & Avella (2013), AR can be highly useful for management since problems are analysed inside the company, in situ, making it possible to close the gap between academic research and firms' activities and needs. With participatory AR, in any specific context, a problem or opportunity for improvement and an academic objective (which constitute the research goal) are identified, a joint action plan is developed, and some results are obtained for both the firm's practitioners and the research team.

Consequently, since both researchers and practitioners actively participate in all the stages of the research, and the aim of the researcher is not to solve a problem for practitioners, but with them. Johansson & Lindhult (2008) consider that through this direct interaction between all the people concerned, AR manages to combine research and development for their mutual benefit. As a result, AR is very recommendable for the implementation of changes and considered to be a very useful tool for improving firms' competitiveness (Alfaro & Avella, 2013; Avella & Alfaro, 2014). Since it favours the success of any intervention in firms' activities, AR is frequently used by organizations to improve their strategies, practices and processes.

Indeed, AR has frequently been used for management research in different sectors (Avella & Alfaro, 2014). In aeronautics, the works on quality management by Prybutok & Ramasesh (2005) and by Prida & Grijalvo (2011) on lean manufacturing implementation can be cited. Our research has specifically focused on problems in the aerostructure final paint area in an SME in the aeronautics sector: a newly established local company designed to respond to the integral management services needs of the aeronautics industry, from raw materials to build-to-print subassemblies. The company's productive organisation is based on three core technologies: machining, surface treatments and assembly.

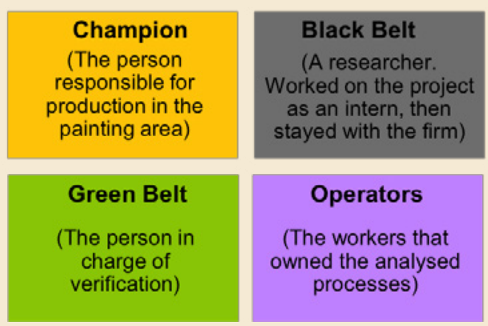
The company in question is local and does not belong to any company group, although it is part of the Andalusian aeronautical cluster. Its position in the supply chain is Tier II. In 2013, the year in which the project was conducted, it had a turnover of €15 Million and a flat functional workforce of close to 150 people, of which 120 were operatives. Average seniority was three years, and there were 10 managers, engineers for the most part. The company had limited experience of continuous improvement projects, which were usually the outcome of customer requirements. The projects were small and on an ad-hoc basis, without any formal development process, and no champion of continuous improvement existed.

The company was experiencing some quality problems in the aerostructure final paint area in some of its contracted programmes. This area generated about 10% of turnover and staff there made up about 20% of the total workforce. The firm's end goal was to solve these problems, and the research team proposed a Six Sigma improvement project, even though theoretically the context was not appropriate.

After both parts had agreed on what, questions on how were also developed together, which started with the creation of a Six Sigma

Committee to address the problems in the painting area. This committee comprised the members shown in **Figure 2**, all of whom were instructed in Six Sigma methodology with the aim of conveying the importance of the project and asking all participants to create synergies that favoured continuity and the rapid deployment of solutions.

Figure 2. **The Six Sigma Committee**



Once the Six Sigma Committee had been instructed, several brainstorming sessions were held to select the specific project to be executed. The problems aligned with the organisation's business strategy that best adapted to the methodology according to the selection criteria (viability, business benefit and impact on the organisation) were set out, with special emphasis placed on the feasibility factor.

Two possible projects were considered for analysis (PG001 and PG002). After analysing these projects on the basis of the definition given in the Project Charters, a project prioritisation matrix (**Figure 3**) was developed with the evaluation criteria that the company considered to be of greatest interest.

Figure 3. **Project prioritisation matrix**

PROJECTS / ASSESSMENT CRITERIA	Impact on costumer	Potential savings	Team availability	Data availability	Fast delivery	Alignment with strategy	Criterion weight x score	Likelihood project will succeed	Final assessment of the project
PG 001	C	A	B	C	B	C	120	+	**360**
PG 002	A	C	B	E	E	A	123	-	123
Criterion weight	ʘ	□	□	ʘ	□	ʘ			

Project criteria matrix
A 5.00 Exceeds the total fulfilment of the criterion
B 4.00 Full compliance of the criterion
C 3.00 Meets essential aspects of the criterion
D 2.00 Partially meets the criterion
E 1.00 Slightly meets the criterion
- 0.00 Contravenes the criterion

Criterion weight
ʘ 9.00 Very important
□ 3.00 Important
▲ 1.00 Slightly important

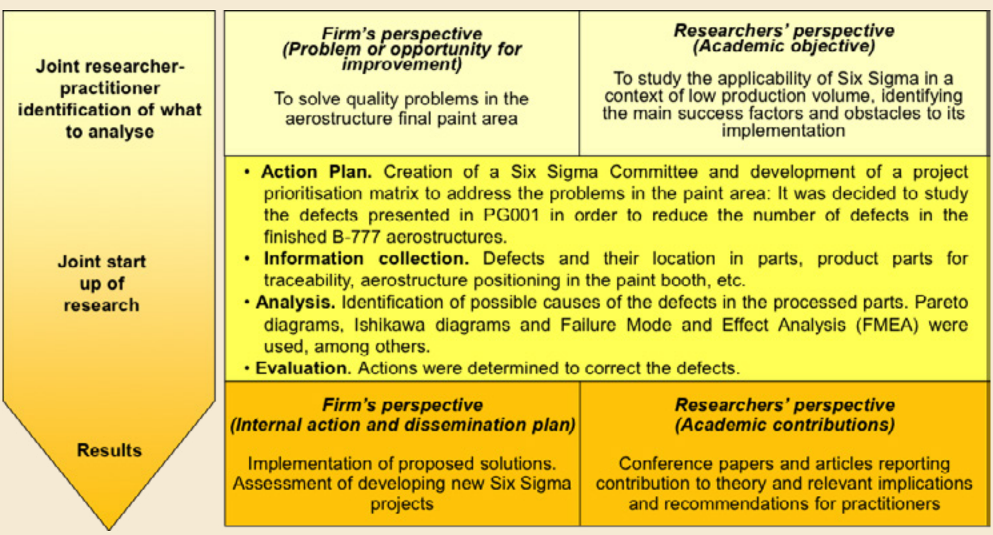
Likelihood of the project succeeding
++ 9.00 Very high likelihood (> 90 %)
+ 3.00 High likelihood (70 % - 90 %)
- 1.00 Risky project (< 70 %)

From this matrix, the Six Sigma Committee decided to study the defects presented in PG001. Production of these elements was about 28 units per month during the analysed period. The improvement pursued consisted of reducing the number of defects in certain finished aerostructures that caused a high rework rate with consequent costs and delays. It must be highlighted that one special feature of this sector that had to be taken into account when implementing the project is that scrap is not permitted and that all pieces have to be checked and reprocessed until they fully comply with customer standards.

A DMAIC cycle was followed for process improvement (Mast & Lokkerbol, 2012), which is the most common way for a Six Sigma project to be executed. Various Six Sigma tools were used at each stage, including Project Charters, Flow charts, checklists, Ishikawa diagrams, FMEA and p-charts.

Figure 4 shows a summary of the goals set, activities carried out and results obtained in this research considering the three basic AR steps suggested by Alfaro & Avella (2013): joint identification, joint start up, and results.

Figure 4. **Action Research developed**



4. RESULTS AND DISCUSSION

With the problem to be addressed in the Six Sigma project duly stated, below we summarise some of the activities performed in each of the DMAIC steps and discuss the results achieved.

4.1. Step 1: Define

In this step, both the project objectives and the constraints were defined, i.e., the problem to be solved and how it was to be measured. The company was aware that there was a serious problem in relation to the project under review. It was known that about 70% of the parts had to be reprocessed but, except for the information provided by the people involved in the Processes (VOE, Voice of Employees), there was a patent lack of data. However, it was estimated that a realistic goal was for the percentage to be reduced to 10%.

A data collection plan was also prepared. For this, both the definition of an NCP (Non-Conforming Product) and the way that the information was to be gathered had to be clarified. For the former, the Critical to Quality features (CTQs, Y variables) included in the customer standards were taken into account. There were 13 of these: pores, lumps, orange-peel effect, cracks, etc. For the latter, check-lists were prepared to collect data on the number and types of defect for each of the references processed, the area where the defects were concentrated on plan types, and the location of the part in the paint booth.

As part of this DMAIC definition phase, a flow chart was prepared of the way that the parts were processed. This included all the operations carried out from the time that the package was signed in to the organisation's facilities until delivery was signed off. The chart was also used to identify and quantify NCP costs that were attributable to reprocessing. These costs could be broken down into labour, paint, power consumed by tools (sander, spray gun, dryer blow gun, etc.), direct process-linked costs (electricity and fuel consumed by the generator) and other non-quantifiable costs. This information was used to make an initial estimate of the total monthly value lost to the quality problems analysed, with the final figure calculated at €3,440.85.

This same information was used to calculate the defect rate per million opportunities (with each of the 13 types of defects listed in the customer standards counted as an opportunity) and, subsequently, the initial sigma quality metric for the process, which was 3.36.

4.2. Step 2: Measure

This phase included executing the information collection plan designed in the previous phase. This plan laid down the parameters that the work team considered that it would be interesting to monitor (defects and their location in parts, product parts for traceability, aerostructure positioning in the paint booth, etc.). Workers involved were also instructed as to the steps in the process; specifically, the inspectors and painters, so that data could be collected efficiently.

Data collection forms were used to quantify these defects according to the most interesting evaluation criteria for decision making as to the conformance of the part. There were three aspects to these evaluation criteria: quantity, size and location. Each of these was measured on a discrete scale of 1, 3 and 9. The arithmetic mean of these aspects provided an indicator of the seriousness of the defect, which enabled part conformance or non-conformance to be specified. Plans/graphics were also used to show where the defects were located on the parts and where these parts were placed in the paint booth.

This phase lasted 5 weeks and the information gathered was used to draw up a sufficiently coherent Pareto diagram to allow some initial conclusions to be drawn. The diagram showed that around half of NCPs were mainly caused by debris. This pointed to dirt and dust in the air and in the paint booth being the main cause of the defects found. The second most common defect (around 13.5%) was caused by the presence of pores during the paint-drying process. These could have been caused by the inadequate preparation of the paint. Finally, silicones (lack of sticking-power) were the third most important cause of defects that resulted in NCPs (around 13%). These three types of defects together fulfilled the 80/20 rule.

As a consequence of the Pareto analysis, some measures were urgently put in place during this period with regard to the cleanliness of the paint booth.

With the data collected during the first four weeks of this phase, defects per million opportunities were again determined and the process' sigma was more accurately valued, with a quality level of 3.42 being obtained. Accumulated losses of €2,479.32 were also calculated during this phase.

4.3. Step 3: Analyse

During this phase, the possible causes (X variables) of the defects in the processed parts and, therefore, their non-conformance, were identified on the basis of the previous considerations and bearing in mind the deep knowledge that work team members had of the process.

For this, a number of both formal and informal meetings were held between the work team (VOE) and operators in the paint area (VOP–Voice of the Process) that enabled sufficient information to be gathered to establish the causes.

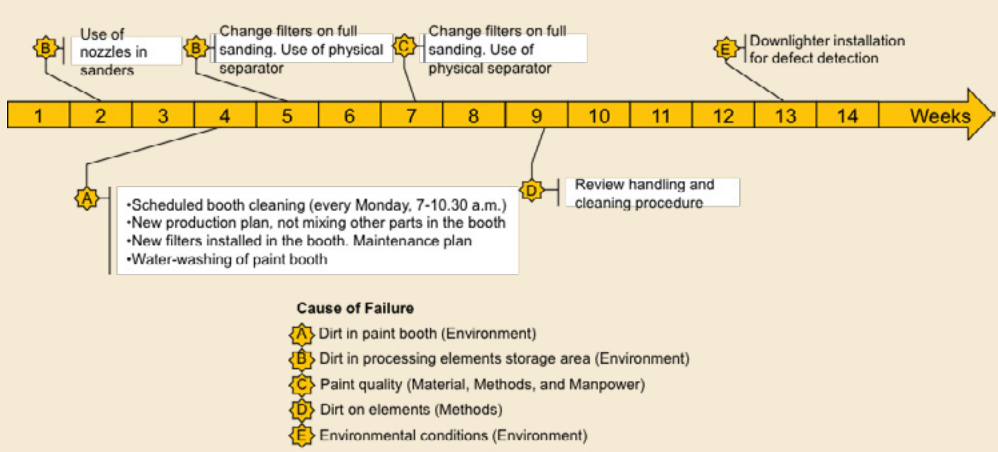
These analyses and the prior considerations that were taken from the Pareto Diagram enabled an Ishikawa Diagram to be prepared to classify the possible causes identified according to the 6 Ms (Manpower, Materials, Measures, Milieu (environment), Methods, and Machines).

A Failure Mode and Effect Analysis (FMEA) was also carried out during this phase for Boeing package aerostructures that included all the considerations made during the project regarding the potential causes that were identified and the effects that they might have. This analysis tool also enabled a list of the most urgent corrective actions to be drawn up according to the Risk Priority Index (RPI) using the product of the seriousness, frequency and detection capability of the causes of failure.

4.4. Step 4: Improve

As indicated, the FMEA carried out during the Analysis phase enabled the causes for the failure mode to be determined and ranked according to the RPI. This was obtained from the tables in the FMEA reference standards. Once the causes had been prioritised, the actions that had to be taken to correct them were determined, and these are set out in **Figure 5**.

Figure 5. **Corrective actions implemented**



4.5. Step 5: Control

The objectives of this step are to validate, verify and monitor the improvements put in place. It seeks to ensure continuity as well as detect and correct any reoccurrence. During this phase, which covered weeks 8 to 11, data collection was done for all the references that had been processed and a p-chart was prepared showing the proportion of defective parts in samples of variable size (each sample corresponds to the number of verifications per week of production). The results of the graph led to the conclusion that the process was under control.

At the same time, follow-up and monitoring of the process indicators during the control phase (percentage of non-conformance products, sigma quality control level reviewed, costs of poor quality, etc.) and the action plans for correction and maintenance established in the previous phases all continued.

Table 2 gives a summary of the steps in the project, indicating their durations and principal outputs.

Table 2. **Summary of the project steps**

STEPS	DESCRIPTION	OUTPUTS	DURATION
Define	• Problem description and identification of CTQs (defects that cause nonconformity). • Definition of current performance. • Definition of the goals of the objectives. • Training of coaching team.	• Timetable. • Six Sigma committee. • Project charters (goals). • Flow charts. • Sigma Metrics: initial estimate	3 weeks (1 to 3)
Measure	• Data gathering regarding current situation. • Identification of possible causes.	• Data collection plan (standardisation). • Sigma Metrics: initial assessment. • Prioritisation of causes (Pareto).	5 weeks (3 to 7)
Analysis	• Data-based identification of causes. • Identification of relationships among variables.	• Brainstorming sessions. • Ishikawa diagram. • FMEA process.	4 weeks (5 to 8)
Improvement	• Prioritisation of causes through FMEA. • Definition of improved process. • Assurance of implemented actions.	• Corrective actions plan. • Process standardisation.	4 weeks (7 to 10)
Control	• Quantification of project benefits. • Project closure communication.	• Metric assessment of improved process. • p-chart for process control. • Monitoring plan of implemented corrective actions.	4 weeks (8 to 11)

4.6. Closing the project and results achieved so far

Once the project was closed, the KPIs could be quantified and the Six Sigma project assessed. During the 2½ months of the fieldwork, process performance measurements were conducted on different aerostructure samples (flaperons and flaps) at three different times. **Table 3** shows the final improvements achieved in the four performance metrics that had been defined and the goals initially set.

Table 3. **Main results: improvements in quality and costs**

METRICS	DESCRIPTION	UNIT	INITIAL	GOAL	AFTER IMPROVEMENT
Y1	Quality level	Sigma	3.35	4.5	3.68
Y2	Rework total time	Hours	75	10	15
Y3	NCP	%	70	10	22.5
Y4	Rework total cost	€/month	3,500	1,000	600

It can be observed that the Six Sigma project can be considered a success in economic terms (Y4), as the cost after the improvement is much lower than the initial goal. These cost savings will be sustained over time and the low costs of implementing the project mean that they will be recovered in a short period of time. In this regard, it is noted that the cost of the researcher who acted as black belt was zero for the company since he worked as an intern, and that the cost of the other employees involved was regarded as an investment by the company, as it was considered to be a learning experience and training. Scheduled corrective actions, such as booth cleaning, filter changes, and the installation of nozzles and lights, did not result in any significant costs.

It can also be considered a success in terms of time devoted to reprocessing (Y2) as, even though the initial objective set was not fully met, a considerable reduction was achieved in only two months. Regarding the percentage of NCP (Y3), we can say that this objective has been met in part, as, although a significant reduction has been obtained, the end result is not as close to the initial target as in the case of Y2. The indicator that has fallen further away from the initial target set is Y1, based on the level of quality (sigma variation).

The lack of maturity of the work team in Six Sigma projects might be the reason why all the objectives were not fully met, and this may be why over ambitious objectives were set for the quality level (Y1) and NCP (Y3). Regarding the first, it is a feature of Six Sigma projects that the mean time required to raise a quality level from 3σ to 4σ is usually around a working year, with the required investment in implementing the actions established and the dedication of the team members involved. It would therefore be of interest to continue collecting data and to keep the action plan in place in order to see how the above indicators develop.

5. CONCLUSIONS

After analysing the results obtained with the implementation of a Six Sigma Project to improve the paint final process of aerostructures in an aeronautics SME, everything points to the high degree of satisfaction of all participants, which contradicts the thesis that Six Sigma is extremely limited in production environments with low production volumes.

Nonetheless, the sector has some characteristics that influence Six Sigma application to a certain degree. Thus, low repeatability, due to the reduced volume of production, makes it very difficult, if not impossible, to achieve the objective of 6σ (3.4 dpmo). In addition, the degree of automation is relatively low, so manual labour, which is subject to greater variability, has greater weight. However, as this and other cases have shown, substantial quality improvements can be achieved through Six Sigma.

On the other hand, workers in this sector are highly qualified, which is an advantage given the intense training required by Six Sigma. Also, items that are produced are of high added value, enabling sufficient resources to be allocated to Six Sigma projects. This may not be the case in other sectors, hampering the applicability and appropriateness of Six Sigma. A further advantage of this sector which favours the application of Six Sigma is the high demand for quality. Other sectors where this requirement is not so high may feel less need to use Six Sigma.

Considering these issues, we believe that SMEs should not rule out Six Sigma methodology, even if it is initially designed for large companies with highly repetitive production processes. This case has shown that it can also be useful for improving processes in SMEs, and that the DMAIC cycle is a practical and easy-to-follow guide for its application, even when work team members lack maturity in the methodology. In fact, the level of Six Sigma maturity is not a predictor of success in executing a Six Sigma project (Nair et al., 2011).

The experience of this study can be used by other SMEs when considering whether or not to use this powerful improvement methodology, which specific tools to use, and some key factors or barriers that would have to be taken into account. The results of this project suggest that the degree of success or failure of the Six Sigma methodology implementation process depends more on the typical key factors of any organizational change (Näslund, 2013) than on the specific industrial sector. These include team commitment, the availability of resources, previous training and, in reference to certain unsuccessful previous experiences, the ability to perform each phase as planned, without any interference. Regarding the latter, it is worth noting that there were certain coercive pressures from the customer while the project was being carried out. These were related to the decision-making process regarding the initial approach to problem-solving and the availability of resources, which, without affecting the continuity of the project, sometimes diverted attention away from the problem in hand. This is a reflection of the importance of one of the critical success factors mentioned in the literature –'linking to customer'– and one of the common barriers to Six Sigma implementation –'not required by customer'.

A future recommendation that the organisation might take into account is the skilling-up of a work group devoted to improving internal processes. While not being subject to external pressures, this group should not neglect any commitments to customers. It should enjoy greater autonomy in these matters, bearing in mind the benefits that have been achieved in a simple project such as the one reported here, the nature of which, moreover, was markedly investigative.

The conclusions reached are not confined exclusively to the analysed company. This company's experience may well be similar to that of other SMEs in this or other sectors, and can be referred to companies who have doubts about the implementation of Six Sigma or who have started its implementation and face some of the difficulties identified in the analysed case.

Finally, we believe it is of great interest to highlight the need for collaboration between practitioners and researchers that is an integral part of action research, the methodology which has supported this work, in order to achieve a balance between the rigor of academic research and its relevance for firms.

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NOTES

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2. The aeronautics industry in Europe is committed to complying with the Advisory Council for Aeronautics Research in Europe’s objectives of minimising environmental impacts during the 2000-2020 period. Known as ACARE 2020, their aim is to make ambitious noise and emission reductions: a 30% reduction in CO_2 emissions, 80% in nitrogen oxides, and perceived noise cut by half. ACARE 2050 seeks to have the industry commit to reducing perceived noise by 65%, CO_2 emissions by 75%, and nitrogen oxide emissions by 90% (Source: ITP (2014): 2013 Sustainability Report. http://www.itp.es/).