Implementation of six sigma methodology for the elimination of contamination in Fine Pitch connectors

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ABSTRACT

Quality drives companies to evolve, providing what customers need or even exceeding their expectations through products and services that play their functions properly during their lifetime. From this perspective, this study aims to solve a concrete defect that occurs during the assembly process of an electronic product for the automotive industry.

One of the new challenges in the electronics industry is the contamination issue in Printed Circuit Boards (PCB). Contamination can be defined as any type of particles (residues) that are deposited on PCB surface or within a component, causing unwanted behaviours in the electronic device.

In the present study, the investigated contamination is organic in nature and is originated by the solder flux. The solder flux is released during the welding process, being deposited inside the PCB Fine Pitch connectors. The DMAIC method was adopted as a Problem Solving tool. This method was selected to ensure the elimination of this type of defect. To support the investigation, the 5W2H and Is/Is Not quality tools were used.

The investigation was developed by a multidisciplinary team. After the root-cause identification, the connectors provider was involved to assist in the development of an effective and low cost solution.

The final solution resulted in the placement in the connectors of a protective cap. This solution, besides protecting the connectors, allowed a new collaborative relationship along the supply chain.

Keywords: Contamination, DMAIC, Electronics, Residues, Six Sigma.

Paper type: Case Study

INTRODUTION

The influence of external factors, such as the global competition and the growing of consumers demand, has generated a pressure on organizations over the years in order to continuously improve the quality level in their goods and services. This new orientation for continuous improvement led to the spread of new Quality Management methods, such as Six Sigma (Fursule, Bansod, & Fursule, 2012; Pešić, Milić, & Stanković, 2012; Sousa & Voss, 2002).

The development that is undertaken by organizations to allow their customers the access to intelligent and integrated devices, has created a new set of challenges, such as the production systems adaptation to handle with the decreasing of dimension of their raw materials (Khare & Maly, 1995). One of the new challenges in electronic industry is the contamination on PCB and their components, which potentiate the failures occurrence in the electronic devices (Steiner, Rendl, & Wirth, 2015).

The Bosch Group founded more than 100 years ago is an organization that, given its size, creates a strong competitiveness in the market. This company's continuous improvement mindset results in a daily ambition to achieve the excellence of their products and processes, as well as in to reduce the huge cost that the company incurs whenever a defect happens.

The opportunity to develop the investigation presented in this paper came from the challenge to analyze and eliminate a specific root-cause that resulted from the presence of a contamination inside of a specific navigation system product.

Therefore, this paper presents a case study that involved the application of the Six Sigma tool supported by the DMAIC method in a electronic components. The DMAIC method was adopted as a Problem Solving tool to support and guide the investigation. This methodology aims to increase the value of the organizations through scientific methods, according to a disciplined logic to improve and solve anomalies of their processes, products and services (Antony, 2014; Choo, Linderman, & Schroeder, 2007; Jacobs, Swink, & Linderman, 2015; Maneesh, Jiju, Jiju, & Madu, 2007; Parast, 2011).

The paper is organized in four sections: the Introduction where a first problem approach was made, the Literature Review to present the state of art about contamination problematic, DMAIC method and Six Sigma, then, the Case Study and, at the end, the Conclusion section where the conclusions are presented.

LITERATURE REVIEW

Contaminations

Contamination can be defined as any residue that can be deposited over PCB surface or inside a component, causing anomalous action in the products (Khare & Maly, 1995). According to ZVEI - German Electrical and Electronic Manufacturers (2014) residue is any particle composed by metal or any other material, such as polymer, minerals or salts.

The contamination thematic has becoming more relevant among electronic industry companies, once this type of defect can compromise the production, quality and reliability of their products (Bumiller, Douthit, & Pecht, 2002).

Duchi & Laügt (2014), Hildén et al. (2015) and Liu, Wu, & He (2014) have concluded that the contaminations are generally associated with some failure modes:

- Short circuits over PCB surface;
- Electrical contacts insulation;

- Electrical conductivity deviation from the expected value;
- Electrical circuits obstruction.

One of the strategies to deal with contamination without doing massive investments is can be through an effective products control. However, as Fernandes & Duarte (2014) emphasize in their, the contamination control is very complex to do, due the independent relation between the moment when the contamination occurs and the moment when its effects are identified (root-cause effect). Another constraint to develop an effective contamination control is related with the difficulty to identify her nature or origin, thus the contamination can occurs, theoretically, in every assembly process steps under a conductive (residues mainly composed by Iron and Zinc) or insulating (residues mainly composed by Oxygen and Carbon) type (Ambat et al., 2009; Smith, 1998).

Among the complexity to do an effective product control, another strategy to deal with contamination was proposed by Komagata (1995). He empathizes that the best way to deal with contaminations is through their sources reduction. The author suggests four steps to do it:

1. Understanding in which step of the process the contaminations may occur;
2. Verify every contamination sources inputs and outputs in that station;
3. Define all potential route causes;
4. Corrective measures implementation.

In summary, the development of the residues thematic is doing its first steps. This area can be very useful to better understand how this type of occurrence can be eliminated, taking into account the current productive systems.

DMAIC method

The DMAIC method is the strategy adopted to implement Six Sigma tool at the operational level, in order to reach the six sigma level. DMAIC is the acronym of “Define”, “Measure”, “Analyse”, “Improve” and “Control” as observed in Figure 1 (Marçola & Politano, 2011).

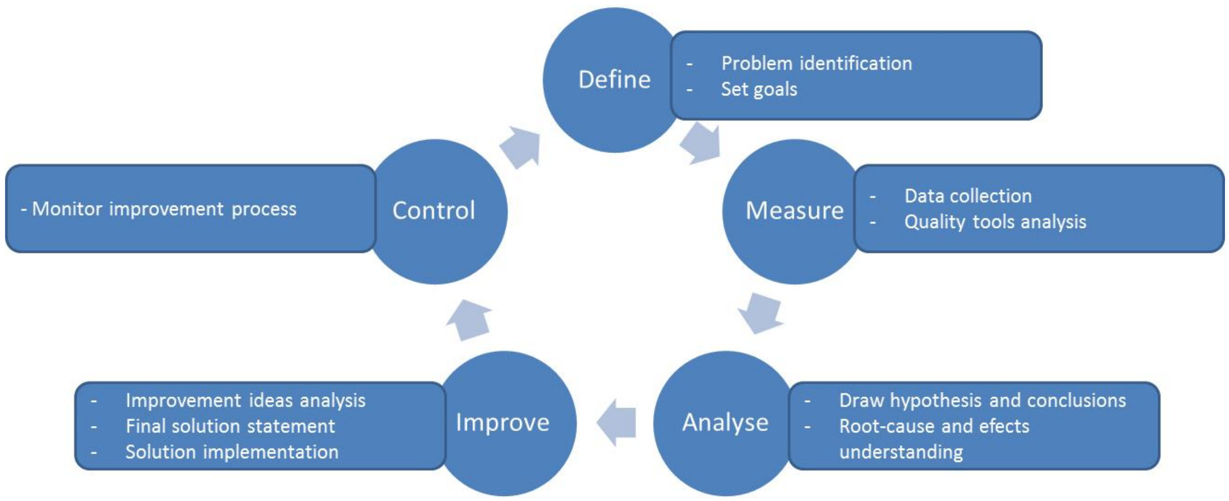

Figure 1 – DMAIC method

Each of these names is associated with each execution phase of the improvement process. A key advantage of DMAIC is the decomposition of complex problems in multiple problems with less complexity, following an incremental improvement logic (Chowdhury, 2002). For this reason, DMAIC method is the most recognized approach in the literature to support Six Sigma projects (Narula & Grover, 2015).

The conclusions of this case study will be analyzed in the ''Control'' phase of DMAIC, by comparing the originally obtained data and the acquired data after the implementation of improvements in the process and in the product under review.

Six Sigma: Definition and Benefits

The Six Sigma tool appeared in 1987 by the initiative of an organization in the communication business, Motorola, which had the ambitious goal of decreasing the defects to a level that had never been achieved before. Motorola self-proposed to achieve a value of 3.4 defects per million units produced, increasing productivity and decreasing costs (Evans & Lindsay, 2002; Folaron, 2003; Mehrjerdi, 2011; Pande, Neuman, & Cavanagh, 2000).

The sigma term arises from the letter ''σ'', present in the Greek alphabet and it is commonly used to represent the standard deviation (Desai, 2015). The term represents the inherent variability of products, services and production processes (Mahesh & Prabhuswamy, 2010). According to Liebermann (2011), the statistical measure of the ability of a process to meet specific requirements - process capability is expressed in terms of sigma quality level (SQL). SQL is the difference between average performance and the specification limit, divided by the standard deviation. A process operating at an SQL of 6 could be expected to have 3.4 defects per million opportunities (DPMO)".

Mehrabi (2012) defines Six Sigma as an approach of management oriented to projects for the implementation of improvements in processes, products and services, in order to continually increase the quality. Notwithstanding and Blakeslee (1999) defines Six Sigma according to an perspective of "Problem Solving". According to the author, Six Sigma can be regarded as a high performance approach, oriented to data, in order to research and find the root-cause, to solve it and prevent future occurrences.

One of the major factor for popularization of Six Sigma was the increasing amount of concrete evidences that large companies have reported in relation to their Six Sigma initiatives in last three decades (Shafer & Moeller, 2012).According to the existing literature on Six Sigma, the success of a project is directly related to the safeguard of some critical factors (Pande et al., 2000). Pande et al. (2000) lists the main critical factors presented in literature:

- Proactive attitude;
- Team work;
- Quality management based on scientific methods;
- Commitment of the organization, from the strategic to the operational level;
- Customer orientation.

Through the change of attitude and genuine application of the above mentioned factors, it is possible to state that there will be a positive change for all performance indicators affected by the Six Sigma projects (Hahn, Doganaksoy, & Hoerl, 2000).

STUDY CASE

The development of the case study took place at Bosch Car Multimedia Portugal S.A. which is one of the leading factories of Car Multimedia division.

The opportunity to develop this case study was born with the challenge to work directly with one of the most complex problems that the company is learning to deal: The contaminations problematic. The investigation main goal is:

The complete elimination of defects (non-conformities) with a root-cause associated to the presence of unknown residues inside display PCB fine pitch connectors, in a specific product produced in Braga facilities.

The case study will be presented following each phase of the DMAIC method.

Define

The analysis of the problem started with the define phase. In this first phase, the initial assumptions of the project are defined as well as the goals to be achieved (Patel & Shah, 2015; Vats & Sujata, 2015). The first process variables are collected and partially analysed in order to obtain the first orientations of what and where are the potential causes for the occurrence of variability not previously expected in affected processes or products.

For the development of the project, a multidisciplinary team has been formed and was composed by:

- Two Black Belts;
- A team leader;
- Quality complaints laboratory coordinator;
- A responsible for quality in production area;
- Customer assistant;
- Project sponsor (Responsible for Customer Assistance, and Process and Quality System sections).

The time frame established for this project was 12 months, oriented specifically to all complaints received by the company from January to December 2015.

Typically, the non-conformities (company claims) were manifested through a change not previously expected in the colour balance of the display in a specific product (Product A) that was produced in Braga plant, as observed in Figure 2.

Figure 2 – Example of display contamination

The adopted metric to check the impact of possible changes implemented by the team was:

Number of defective units due to contamination

Measure

In the measure stage, the non-conformities are validated and an intensive data acquisition was started in order to understand the current state and to obtain a first approach to understanding of the problem's root-cause (Barbosa, Carvalho, & Pereira de Souza, 2014; Vats & Sujata, 2015).

There is a big concern in the company to understand and eliminate this type of contamination due to the difficulty to achieve and maintain the quality standards that are set by the client during the contract definition.

To study and characterize in detail the occurrence of non-conformities, in absolute values, the team used some tools such as the 5W2H and Is / Is Not tools, in the time frame previously established, as shown in Table 1.

Table 1 – 5W2H and Is/Is Not analysis

Problem:			Display: Color balance alteration	
Collection of Facts		Nº	IS	IS - NOT (but could be?)
What?	**Object** with defect (supplier, producer, customer, application)	1	Product A, Customer A	Product C, Customer B
	Defect on the object (from analysis)	2	Connector Fine Pitch xxxx1 with isolator residue	Connector xxxx1 with no contact due to bent pin
Where?	**geographically** is object with defect observed?	3	Belgium plant (customer plant) United Kingdom plant (customer plant)	Germany plant (company plant) Braga Plant (company plant)
	in the process is the defect observed?	4	4 defects - United Kingdom plant 5 defects - Belgium plant	-
	on the object is the defect? (from analysis)	5	Display Product A (Customer A)	Fascia Product C (Customer B)
When?	did object with defect occur **for the first time**?	6	17-02-2014	Beginning of Product A (Customer A) Production
	again (trend, rhythm of occurrence)?	7	Intermittent: 07-03-2014, 05-06-2014, 01-07-2014, 21-08-2014, 13-09-2'014, 22-10-2014, 30-10-2014, 17-12-2014	Constant
	in the life cycle of the object was the defect observed?	8	0Km and field	FOR
Who?	discovered the defect?	9	Customer A Assembly line operator and final Customer;	Braga plant Quality Gates Operator
How many?	**How many objects** show the defect?	10	9	-
	How much of the object is affected?	11	In one contact pin of the connector	More than one pin
	How many **defects** are **on the object**?	12	1	More than one
	Trend	13	Constant or increase	Irregular

Through the use of these two tools, the team obtained some conclusions:

- The total number of non-conformities claimed by the customer during 2014 and 2015 was 9 Units;
- All claimed units were produced in 2014;

- All non-conformities happened due to the low electrical conductivity in a connector (fine-pitch type), responsible for establishing the connection between the display and the main printed circuit board (PCB);
- Defect occurrence is chaotic and no temporal pattern is observed;
- All defects were manifested in customer internal quality control (0km) and in final-customer (field).

Analyse

At this stage the team seeks to formally identify the causes that were leading and influencing the occurrence of certain problem (Patel & Shah, 2015; Sadraoui & Ghorbel, 2011).

With the support of technical documentations from the product and of the diagnostic tests performed by technicians at the quality complaints laboratory, it was understood that the problem's root-cause was related to the presence of a residue on the surface of the connector pins. This residue acts like a barrier that limits electrical conductivity between the PCB display connector and the main PCB, as observed on Figure 3.

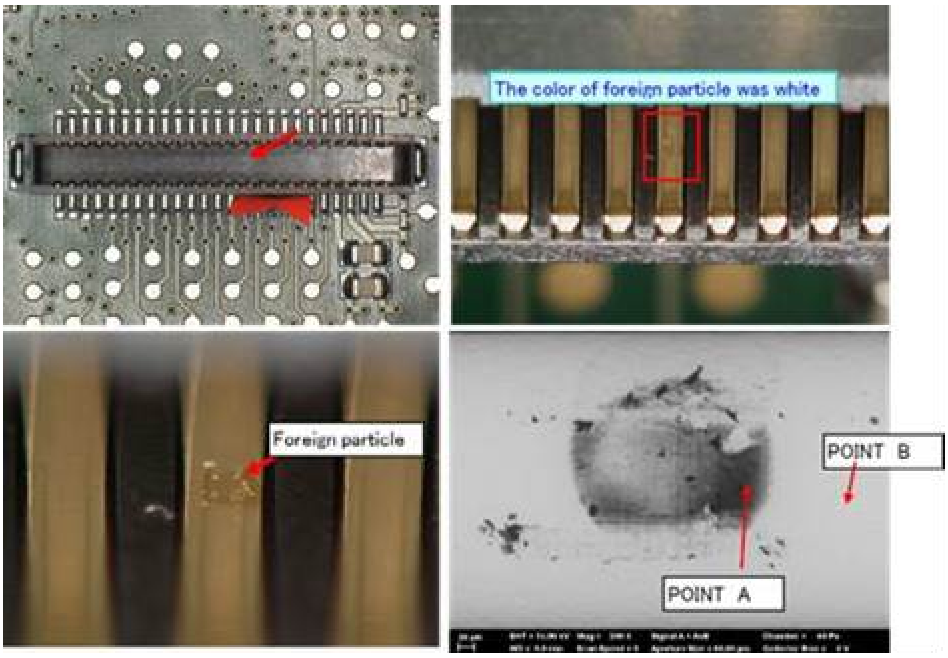

Figure 3 – Residue photos with different expantion lens

As observed on the photo from lower right corner (Figure 3) the residue has a drop shape. In all analysed products, this type of shape was observed, but the existence of a location pattern was not observed, once in each affected product, the residue was found in different connector pins.

Usually, when non-conformities are related with residues presence, laboratory technicians request two type of analysis in order to try to find their origin and composition:

- SEM analysis: Scanning electron microscope is a technique to analyse and examine microstructural characteristic of the specimen surface through the creation of a surface picture with a zoom between 1000 and 20000X (Fu, Croarkin, & Vorburger, 1994; Goldstein et al., 2012);
- EDS analysis: Energy-dispersive X-ray spectroscopy is a technique usually used to know the chemical composition and concentration of each element that constitutes the specimen (Amjad, 2013).

Given the results obtained from EDS analysis, it was concluded that the residue was mainly composed by organic elements as Oxygen (O) and Carbon (C).

Once the residue is of organic origin, the next requested technic to analyse was the FTIR analysis. FTIR or Fourier Transform Infrared Spectroscopy is a technic developed to characterize organic compounds (Wilson, Decius, & Cross, 2012).

In every FTIR performed to each claimed unit, the same characteristic curve was always obtained. From this result the team invited a company specialist in FTIR analysis to participate in a brainstorming session, where the guidance to research the solder used during PCP assembling process arose.

After comparing the FTIR characteristics curves of the residues found in each claimed unit with the FTIR of the solder used during the reflow process, a positive match was observed. In order to eliminate any possibility of error, the team picked up a sample of the solder during this process and requested a new FTIR analysis. Again, a positive match was obtained.

Given this positive match between the residue and the weld sample, it was understood that the root-cause from the change in colour balance of the display was originated during the reflow process with solder flux. After that conclusion, the team oriented the investigation to the reflow process of the PCB with the affected connector. The reflow process consists on the process of soldering the electronic components to the PCB. After the placement of solder paste on it, the PCB is controlled by video cameras to verify its correct distribution on the PCB's surface (Step A). Then the components are placed over the solder paste (Step B). When the step B is finished, the PCB enters in the oven with an atmosphere rich in nitrogen, which will gradually warm up until the reflow temperature. During this temperature gradient the solder paste turns to a viscous state, the solder flux evaporates and the gas is released to the oven atmosphere (Step C). In this point, the temperature gradient starts to decrease and the PCB leaves the oven, where a new quality control to evaluate the components solders happens (Step D).

During Step C, there is an interaction between different thermodynamic phenomena, including:

1. Temperature movements, firstly ascendants and then descendants, called temperature profile;
2. Different gases concentrations in oven atmosphere during the temperature profile.

Taking account these phenomena the team developed two hypotheses for contamination occurrence:

1. Ineffective or insufficient maintenance of the oven that can generate a high level of solder flux gas in oven atmosphere, due to the presence of solder flux debris inside oven retention grids;
2. Deposition of solder flux particles inside the connector due to temperature alteration.

Hypothesis 1 was not considered after its analysis. The team investigated the cycle of oven maintenance and the process of oven cleaning and concluded that there is not a direct influence between the production dates and oven maintenance. For this fact, the team started to investigate hypothesis 2.

In detail, hypothesis 2 extrapolates that, inside the connector, a deposition of solder flux particles in suspension on oven atmosphere occurs due to a thermal difference between the end of the heating and the beginning of the cooling process (interface zone), as schematized in Figure 4.

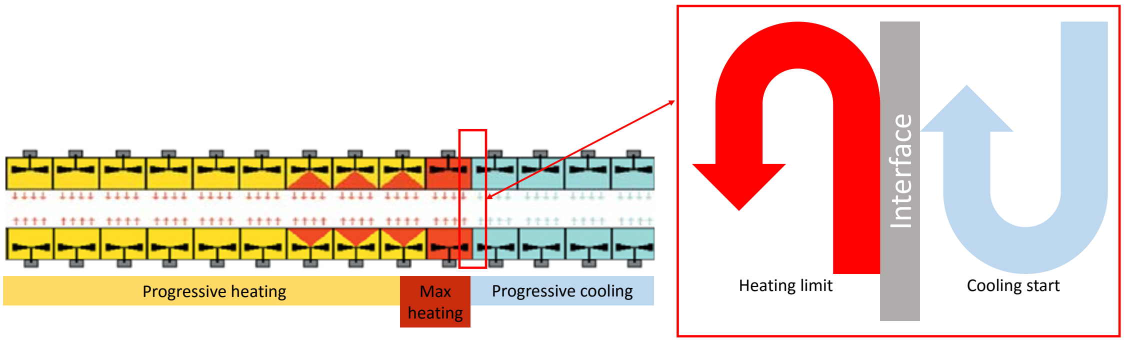

Figure 4 – Interface Heating-Cooling schema (Adapted from Juki Automation Systems (2015))

A team of experts in the maintenance area, conductive solders and thermodynamics was formed for a brainstorming session with the project team. In this session, it was empirically concluded that the solder flux (in the form of particles in suspension in oven atmosphere) is deposited on connector pins surface due to the occurrence of some events, such as:

- High density saturations of soldering flux at the bottom of the retention grids;
- Incomplete passage of solder flux to the gaseous state;
- Connector architecture.

Improve

At this stage, after the clearly identification of the root-causes, the team develops several ideas and propose solutions to eliminate the problem. At the same time, a study to know and prevent negative side effects was developed, derived from changes in the process or in the product (Júnior, 2007).

In this project development phase, the team identified three proposals to analyse and selected one to be implemented. The three proposals were:

1. Replacing the reflow oven by a new one with better technical characteristics;
2. Isolation of the connector with thermal tape;
3. Development of a specific connector cap.

Proposal 1 was discarded because it was an investment that would amount to several hundred thousand of euros. This investment would be only amortized after the end of product production.

Regarding proposals 2 and 3, the team analysed some aspects as economic impact, difficulty of implementation and result achievement.

In terms of economic impact, proposal 2 has an impact of 124.5€ per 100 PCB lot, while proposal 3 causes an economic impact of 14€ per batch of 100 PCB. To calculate the economic impact it was taken into account the raw material cost, labor cost and operational time cost.

About the difficulty of implementation, proposal 2 could be done inside Bosch plant, whereas proposal 3 needs to be implemented by the connector supplier. Another obstacle to the implementation of proposal 3 is the necessity to redefine the supply contract.

Finally, proposal 2 was not technically valid, because the thermal tape could only be applied on the connector after the reflow process. Therefore, proposal 3 is the only that ensures the permanent elimination of the non-conformities.

Therefore, the selected measure (corrective measure) was proposal 3.

This solution can be described as the colocation of a plastic cap, specifically designed for this connector type, as schematized in Figure 5.

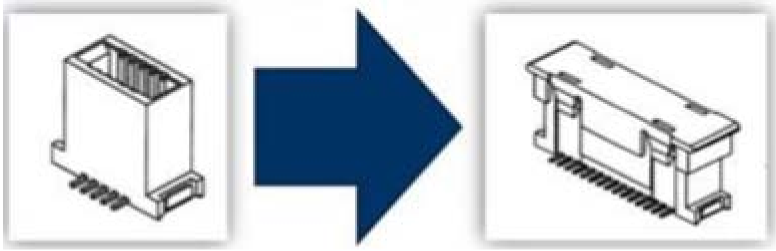

Figure 5 – Connector schema without and with the plastic cap

The cap is placed above the connector in Bosch supplier and removed during the assembly process, allowing a reduction of manpower cost and ensuring that the connector is protected during the whole reflow process and partially during the final product assembly.

A plus of this proposal was the integration of the supplier during the design process. This integration allowed an approximation of both companies to improve supply-chain quality.

Control

This is the last stage of DMAIC method. In this stage new processes are developed to ensure the maintenance of the performed improvements and, the changes in process or product are controlled in order to evaluate their effectiveness (Barbosa et al., 2014).

The corrective measure was implemented in September 2015. In order to ensure the control effectiveness, the team defined a time frame of six months, from September to February 2015, to verify the occurrence of other contamination.

After the end of the control period, no contamination was reported and, by this fact, the team was congratulated to have achieved the project main goal.

CONCLUSION

The investigation presented in this paper showed that Six Sigma tool is flexible and is able to adapt in order to solve problems, regardless of the process or product. This conclusion converges with the generic consensus found in the literature.

During the development of each DMAIC phase, this method allowed the decomposition of complex problems in multiple simple problems, in a disciplined order.

The use of the 5W2H and Is/Is Not tools allowed the achievement of a high degree of process understanding and non-conformity knowledge. The good understanding of the reflow process was a key factor that contributed to find the root-cause with low resources.

Additionally, regarding the tools used during the investigation, the Process Plan Sheet of residues inputs and outputs could have been used. It was not used because, in the process under analysis, the number of inputs and outputs was very small, taking into account the insulating nature of the particle.

The contamination sources identification proposed by Komagata (1995), during the Analysis phase of the DMAIC was used for the first time in the company. This approach guided the team for what and where should be investigated. In the past, according to the team experience, the residues investigation was made without the support of any disciplined approach. It was a trial and error process. For that reason, the company made another step to learn how to handle with the contaminations problematic.

Regarding the case study, despite the involved variables complexity, it was possible to reach the main goal of eliminating permanently the non-conformities, even without any scientific validation of the empirical conclusions and extrapolations that were made during the Analysis phase of the DMAIC method.

The adopted solution for permanent elimination and prevention of contaminations (regardless of their origin) inside connectors resulted in a lesson learned that will be taken into account for future products.

In the area of supply chain, an intensive investigation was made and another interesting conclusion was reached. A differentiating strategies consists in the creation of collaborative relationships between the stakeholders along the supply chain, in order to increase the products quality and operational efficiency.

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