**POLITECNICO DI TORINO**

Department of Mechanical and Aerospace Engineering

# WORLD CLASS QUALITY

## FROM ISSUE TO LESSON LEARNED

Description and commentary of the study carried out in the quality department of FPT Industrial

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**Case of Study – Lambda Sensor Drifting**

# Ringraziamenti

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# Abstract

Quality problems management is a crucial point for companies with high production volumes and marked demands. Quality issues are critical factor to manage, since they imply money and time losses, leading to a decline in customer's perception of the brand. In this context, rapid and effective methodologies and tools are necessary, to streamline the trouble-shooting procedure, thus reducing wastes. The reactive approach phase to a problem is therefore managed in a logical and structured manner and is always followed by an extension of the knowledge that gives the possibility to act proactively. This thesis work aims to extend the concepts, ideas and tools of World Class Manufacturing in qualitative field, specifically in problem-solving stages. Total Quality Management and Kaizen techniques are therefore adapted to the Product Quality Support division, which plays the fundamental role of solving quality issues. Starting from statistical data and performance indices analysis, a targeted cost deployment is applied in order to attack the root-causes that generate the most important qualitative problems.

## Paper Structure

The paper is divided as follow: the *introductory chapter* explains the shift from a mass production based on quantity, to a lean production based on quality, arguing the concepts of kaizen and quality management system.

*Chapter two* introduces the concept of quality, which often presents nebulous and subjective definitions, describing TQM (Total Quality Management) and its most important tools.

A company that aims at a leadership in the world market must be a World Class Company. For this reason, *chapter three* describes World Class concept, born for the manufacturing, extrapolating ideas and methodologies that can be applied in quality field. World Class techniques are applied to trouble-shooting, and *chapter four* describes the problem-solving stages, set according to a Kaizen philosophy (PDCA).

The *last chapter* analyzes a practical problem-solving case addressed in CNHi. Starting from a cost deployment, the main KPIs have been analyzed. From here, the worst component of the After-Treatment system has been studied and the world class problem-solving method has been applied in order to obtain results and improvements in an efficient way. Furthermore, from the resolution of the problem a lesson learned has been obtained that will be horizontally extended within the company.

## Abbreviations

| | |
|---|---|
| ACPU | Average Cost Per Unit |
| ATS | After Treatment System |
| B/C | Benefit over Cost |
| CORF | Customer Observed Repair Frequency |
| ECU | Electronic Control Unit |
| FPT | Fiat Powertrain Technologies |
| ISO | International Standardization Organization |
| KPI | Key Performance Index |
| MERF | Manufacturing Engineering Repair Frequency |
| PDCA | Plan Do Check Act |
| PI | Priority Index |
| PQS | Product Quality Support |
| QMS | Quality Management System |
| SE | Sensing Element |
| TPB | Three Phase Boundary |
| TQM | Total Quality Management |
| WCM | World Class Manufacturing |
| WCQ | World Class Quality |

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*“Textbooks aren’t the real world. The information we use comes from years of empirical testing…”*

Tom Rhines

# CHAPTER 1

## INTRODUCTION

# 1. Introduction

During half of nineteenth century, Frederick W. Taylor studied a theory regarding the scientific organization of the work. This theory was based on the concept that each worker has a specific task to do in a specific time and in a specific way. Each production cycle's operation can be divided and studied in detail, in order to identify which is the best and more efficient way to perform it, deleting unnecessary effort, and introducing selection of the workers.

Thanks to the application of these principles, the first assembly chain was born, giving life also to a new workman figure, to which the "Taylorism" removed all kinds of discretion. In fact, while the worker previously could choose the times and the ways of his work, with the introduction of the new procedures he was forced to adapt rhythms and methods chosen by the executives.

Taylor said that the workers could not organize the work, but is the company itself, the management that has to take decision also for the worker, that has the only task to do systematic and very simple actions. This way of thinking is called "Task Management".

**Fig. 1 -** Ford Model T Poduction Line

These ideas could be applied in industrial field, in order to take the advantage of an high efficient and mass production, aimed to high level of production with very standardized products.

Henry Ford, was the first to apply these concept in industrial field. In fact, in 1907 announced his goal for the Ford Motor Company: to create "a motor car for the great multitude." At that time, automobiles were expensive, custom-made machines.

Ford's engineers took the first step towards this goal by designing the Model T, a simple, sturdy car, offering no factory options. The Model T, first produced in 1908, kept the same design until the last one rolled off the line in 1927. From the start, the Model T was less expensive than most other cars, but it was still not attainable for the "multitude." Ford realized he would need a more efficient way to produce the car in order to lower the price. He and his team looked at other industries and found four principles that would further their goal: interchangeable parts, continuous flow, division of labor, and reducing wasted effort.

Using interchangeable parts meant making the individual pieces of the car the same every time. That way any valve would fit any engine, any steering wheel would fit any chassis. This meant improving the machinery and cutting tools used to make the parts. But once the machines were adjusted, a low-skilled laborer could operate them, replacing the skilled craftsperson who formerly made the parts by hand. Each worker was trained to do just one of these steps. Ford called in Frederick Taylor, the creator of "scientific management," to do time and motion studies to determine the exact speed at which the work should proceed, and the exact motions workers should use to accomplish their tasks [1].

The assembler had the only task for instance to put nuts on bolts, or attach one wheel to each car. He didn’t have any other contour role, such as order parts, procure his tools, inspect for quality or even understand the whole process in which he was involved. For that tasks there was specialized men, such as engineers, inspectors for quality and defective work. The assembly worker had the lowest status in the factory, and, according to the Ford way of thinking they were needed only because automation could not replace them [2].

The limitation of the Fordism and of its high structured, rigid and standardized methodology was that it was highly dependent on the market request. In fact, this "push" concept, was based on a potentially infinite marked demand, in which was the company to decide the production rate, that could be the highest possible. This push production requires a marked demand that is higher than the offer.

During 70's the most industrialized countries faced a saturation of the market, with a reduced demand lead only by the substitution of a product. This phenomenon induced a demand lower than the offer, that is translated in a non-efficiency of the push-ford model. The customers required a diversified and customized product that was feasible only with a flexible production.

In contrast to the rigidity of the Fordism, the flexibility was the key word aimed to accomplish a continuously changing market. Instead of producing generic goods, firms now found it more profitable to produce diverse product lines targeted at different groups of consumers, appealing to their sense of taste and fashion. Instead of investing huge amounts of money on the mass production of a single product, firms now needed to build intelligent systems of labor and machines that were flexible and could quickly respond to the whims of the market [3].

The flexibility was a concept applicable at each field. Indeed, was important a flexible labor, a flexible product and a flexible productive quantity, in order to deal with a lower break-even point by setting as priority target the cost reduction. The bureaucracy should be deleted, and fixed cost must be cut down in order to have a rapid reprogramming of the productive line reacting to the market in real time.

Fordism main concept is based on a production planning dealing with a highly predictable market, instead the post-Fordism has a reactive strategy, avoiding heavy investments in order to adapt in a continuously changing environment.

## 1.1 From Quantity to Quality

As mentioned in the previous paragraph, during the Fordism years, the whole world needed to be motorized. This was possible thanks to mass production, which guaranteed high product quantities at low prices.

Quantity was the key word: the market demand was high, and the competition virtually zero. The high standardization guaranteed high volumes with reduced tac time.

On the other hand, very often quality was neglected, not being considered a cornerstone of the production system. The quality management system was only guaranteed by statistical end of line checks. Countermeasures were done by discarding failed pieces. There was not an effort in reducing wastes. The high production and therefore the high profit, did not justify an excessive expense in quality and thus problem prevention.

This brute-force problem solving approach was no longer effective as market faced saturation.

| | FORDISM | POST-FORDISM |
|---|---|---|
| *Principle* | Rigidity | Flexibility |
| *Dimension* | Gigantism | Lean |
| *Esecution* | Sequencing | Programmability |
| *Company Organization* | Hierarchy | Horizontal |
| *Spacial Organization* | Centralized | Decentralized |
| *Strategy* | Planning | Reacting |
| *Comunication* | control | interaction |

**Tab. I** – Comparison between Fordism and Post-Fordism

Acting and being a leader in a competitive market requires not only excellent product performance, but also quality and reliability that meet customer expectations.

This quality level can be achieved extending the quality concept to every company division: the quality must be total (TQM, Chapt. 2).

Furthermore, the concept of production must change perspective, moving from a quantity-based-production (Mass Production), to a production that faces a quality, waste and costs reduction philosophy, called also Lean Production.

## 1.2 Lean Production

### *1.2.1 From Fordism to Toyota Production System*

As explained in the previous paragraph, during the second decade of twentieth century, production volumes were high to justify an high-speed assembly line, guarantee by the ford production system. Vehicle were not complex items to build, and quality was not a central concept in the production system.

During the final years of 1940, Toyota was a small company, with very old machines and small production quantities. Taylorist-Fordist criteria could not be implemented, since there was not the possibility to set-up a production line, that should involve the use of an high number of performant machines.

Japanese production model, was based on the industrial reorganization, re-evaluating the human contribution in terms of intelligence and responsibility. What emerges was a new managerial innovation framework. Taiichi Ono, the head of Toyota, decided to adopt new solution, different from the rigid Fordist system. Its idea was to produce lots in short periods, trying to respond immediately to market changes, and the production would be scheduled continuously.

These concepts led to a pull production, and not push production as happen in Ford Production System. The produced quantities are closely related to changes in real demand.

The worker is no longer a mere executor of orders, but it has an active role in the company, also being able to intervene on the production itself. The work is now organized around production cells, and workers are also involved in Quality checks. Quality assumes an important role. Complexity of product increased, and sophisticated quality assurance and control gave birth to large quality control functions [4]. Produced vehicles are highly customized, and several lean methods are needed to spot errors, such as Kaizen, 5Whys, Poka-Yoke, 5S [5].

### *1.2.2 Post-Fordism and Lean Production*

The post-Fordism led to the development of a new production concept, that was an important evolution of the mass production system. The lean production, or lean manufacturing, is a completely new concept that try to extract the maximum from the available resources, in term of human, material or capital resources [6].

It is basically a systematic method for waste minimization without sacrificing productivity, increasing the value of the product in each action performed, reducing everything else. Indeed, it is aimed to reduce the level of input resources for a given level of output.

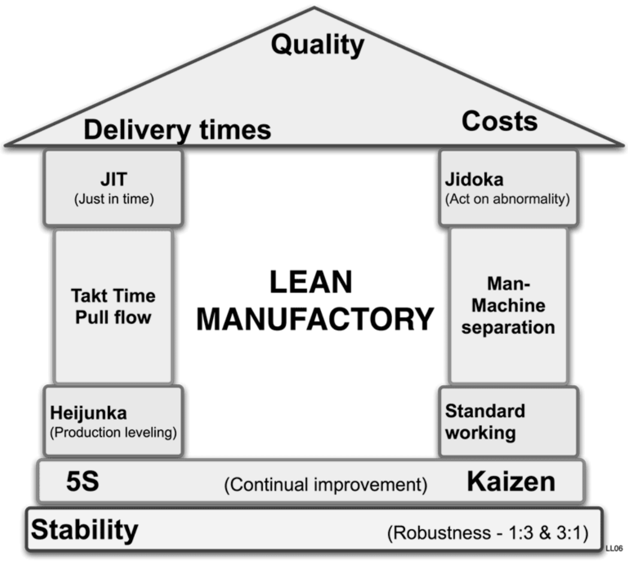



**Fig. 2** - Lean Manucaturing House

The concept of waste has to be defined in a correct way. In fact, waste is any human activity which absorbs resources but create no value. Thus, waste has to be intended not only as physical loose of material, but also in term of time, of effort, of money. It is anything of unnecessary, that has not the aim of add value to the final product.

These concepts were firstly introduced by Taiichi Ohno and Eiji Toyoda, and applied in automotive field for what concern the Toyota Production System (TPS). The TPS is a production system aimed to design out overburden (muri) and inconsistency (mura) eliminating all types of wastes (muda).

Taiichi Ohno defined seven groups of activities that can create muda [7]:

- Overproduction
- Waiting (for the next step)
- Transport (unnecessary movement)
- Over Processing (rework and reprocessing)
- Inventory
- Movements
- Defects

As said before, these seven groups of muda are related not only to the production system, but also to any other activity performed in a company.

However, the most important muda to be avoided is Defects. For this reason, to reach a perfect lean production, the main goal is to have a zero-defect production, meaning error free parts must be obtained from very beginning of the value stream. TPS avoided a check of each part to detect the defects, but the task of finding defective parts was in the responsibility of everyone and not only the quality control personnel. Identifying and fixing errors is a responsibility of all workers, controlling the whole process to find errors that can cause the defective part, acting in a preventive way.


**Fig. 3** - 7 Wastes Representation

## 1.3 Cost Reduction

Cost reduction is the process used by companies to reduce their cost and increase their profits. The strategy of cost reduction can vary depending on the type of product, on the competition and on the market share a company is focusing.

Several factors can affect the cost, but the most important are related to development cost, engineering cost, manufacturing cost and quality cost.

In order to reduce the cost of a single product it is important to focus on the organization of these divisions and on the method they use to perform any action. It is important to standardize a methodology, organize the work structuring a defined process and flow of work to reach the company final goal: reduce waste and increase income.

## 1.4 Kaizen Concept

Cost reduction can be achieved also by investing money. Even if this action can be seen as an increase of cost, it is important to consider the impact in future years. Investing in continuous improvements is a strategic action for a leader company, that can lead in a reduction of wastes and thus of cost.

For that reason, in Japan during the TPS development was introduced a completely new and revolutionary concept, called Kaizen.

Kaizen is a Japanese word for "Continual Improvement", referring to activities that continuously improve all functions and involve all employees, from CEO to the assembly line workers. It can be applied in each process such as purchasing, logistic, development, engineering, quality and so on.

The value of improvement is an important concept. In business, whenever improvements are made, they are eventually going to lead to better quality and productivity. Improvement is a process that start recognizing a need that become apparent when you recognize a problem. For this reason, Kaizen is aimed to put an emphasis on problem-awareness and will lead to an easier identification of the problem.

The core principal of kaizen is thus to make small, immediate improvements in the process and standards of the workplace. But not just one improvement. Looking for ways to make small improvements should be part of everyone's job, every day of the week. Continuous improvement of processes and products as well as the responsibility of all workers for quality are fundamental guidelines of TQM philosophy – that will be explained later on – conducing to the increase of the productivity without simultaneous decrease of quality [8].

When a worker recognizes a problem, kaizen is already working. The real issue is that people who create the problem are often not directly inconvenienced by it, and thus tend to not be sensitive to the problem. In day-to-day management situations, the first instinct is to hide or ignore the problem rather than to correct it, since by nature nobody wants to be accused of having created a problem [9].

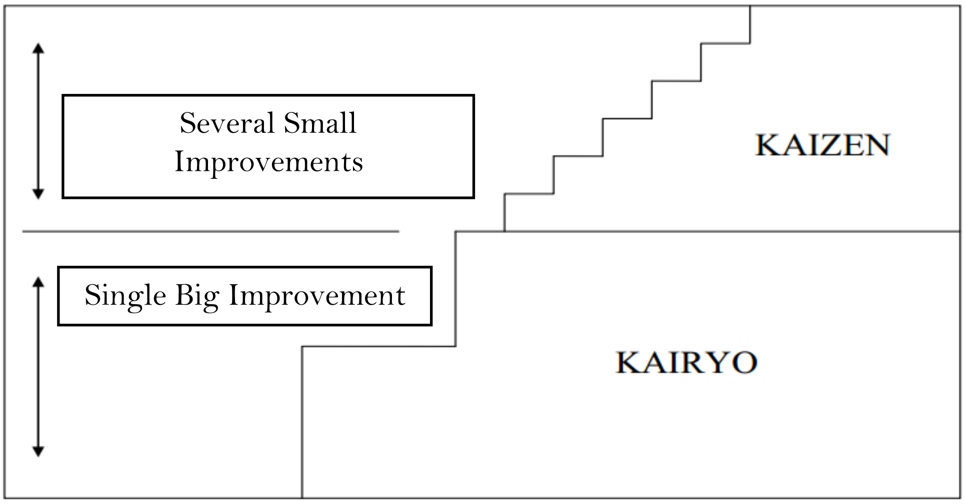



**Fig. 4** - Kaizen and Kayro confront

Even if both kaizen and innovation lead to an improvement, there is a huge difference between them. Kaizen is in fact focused on small improvements as a result of progressing efforts of the company's staff members. On the other hand, innovation is focusing on large, dramatic improvements as result of big changes in technology and equipment. It is a step that cannot be implemented in one day, but requires something lasting months, or years.

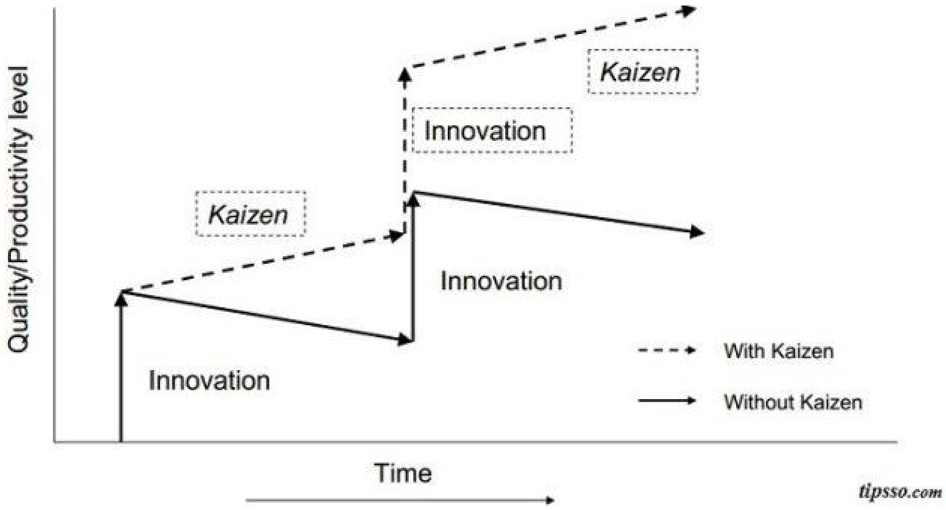



**Fig. 5** – Kaizen and innovation steps

Another difference from Kaizen, is that innovation can result in non-incremental result. For instance, concerning delivery time of a product, innovation will rebuild all process incorporated into delivery that could lead for the days after the implementation a drop of quality of productivity due to the implementation of new system. Last but not least difference is that kaizen does not need big investments, opposite, innovation will need larger investments in time, money and efforts.

## 1.5 Kaizen Implementation – Quality Management System

The kaizen activity can be implemented using the PDCA cycle. It is a process approach for implementing the Quality Management System, and is complaint with the ISO 9001 requirements. This methodology can be applied to each process or department of a company.

Basically, it has 4 main phases:

- Plan
- Do
- Check
- Act

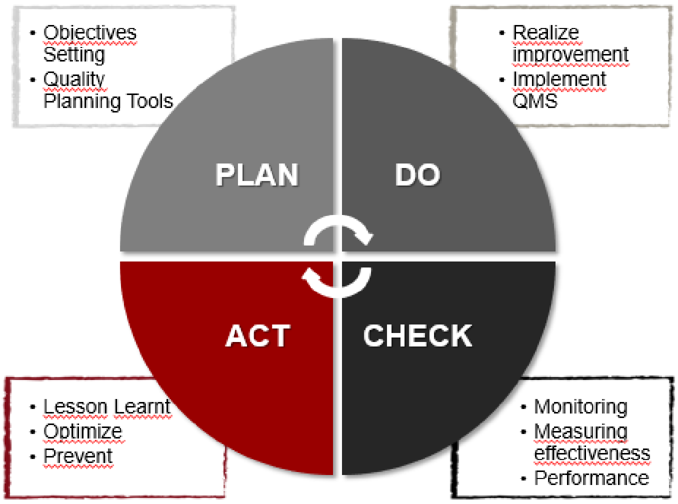



**Fig. 6 -** Plan Do Check Act Cyrcle

The Plan phase, establish the objective and processes necessary to deliver results in accordance with the expected output. By establishing output expectations, the completeness and accuracy of the specification is also a part of the targeted improvement. When possible start on a small scale to test possible effects.

Planning is useless unless the plan is carried out. During the Do phase, the plan is implemented and the process executed (often on small scale if possible). Data are collected for charting and analysis in the following check and act steps.

The check phase measures the new process and compare the "Do" results against the expected results to ascertain any differences. Look for deviation in implementation from the plan and also look for the appropriateness and completeness of the plan to enable execution. Charting data make this much easier to see trends.

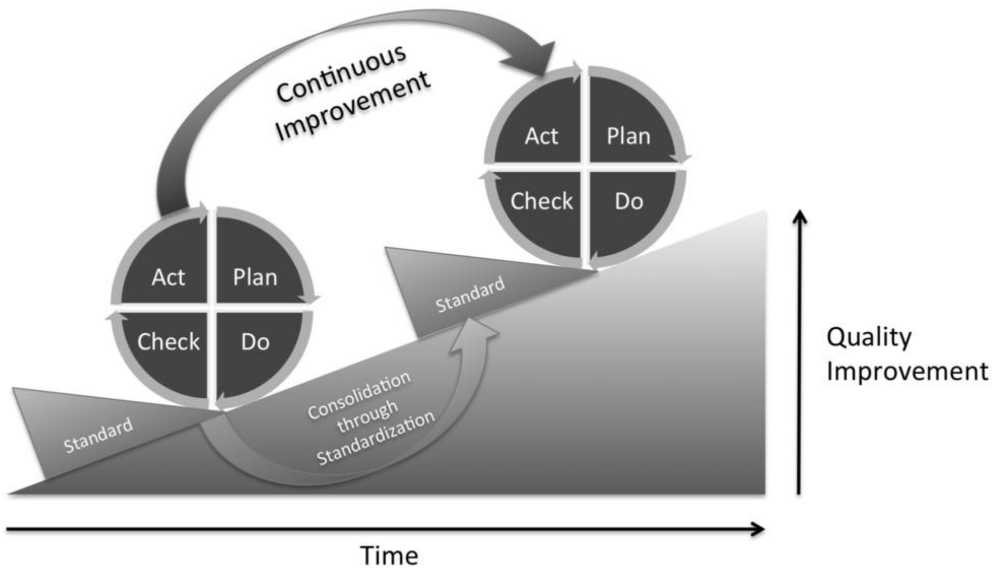



**Fig. 7 -** Innovation Process and Kaizen Iteration

If the check phase shows that the plan phase (which was implemented in do phase) is an improvement to the prior standard, then that becomes the new standard. The act phase involves making adjustments or corrective actions, but generally it would be counter to PDCA thinking to propose and decide upon alternative changes without using a proper plan phase, or to make them the new standard without going through do and check steps.

The PDCA cycle is thus a system to ensure the continuation of the kaizen principles, ensuring a methodology to find problems and act with an immediate solution that will lead to new standard.

# CHAPTER 2

## TOTAL QUALITY MANAGEMENT

## 2.1 Quality Definition

From customer's point of view, if a product fulfills the customer's expectations, the customer will be pleased and consider that the product is of acceptable or even high quality. If his or her expectations are not fulfilled, the customer will consider that the product is of low quality. This means that the quality of a product may be defined as "It's ability to fulfill the customer's needs and expectations". Quality can be defined in terms of parameters or characteristics, which vary from product to product. For example, for a mechanical or electronic product these are performance, reliability, safety and appearance [10].

An IVECO and Mercedes truck are for instance equally "fit for use", in the sense that they both provide automobile transportation for the consumer and each may meet the quality standards of its individual purchaser. However, the two products have obviously been designed differently for different types of consumers. This is commonly defined as the quality of design – the degree to which quality characteristics are designed into the product.

However, the quality conveys notions of nebulous factor that are not readily measured or tied down. For this reason, is important to pin down a quality definition that can be adapted to manufacturing process from the firm's point of view. It can be defined as a conformance to standards defined by the producer, to give the ability to measure it in physical parameters of conformance to standards and specifications.

Thus, one can say that the two perspectives are dependent on each other. Although product design is customer-motivated, yet it cannot be achieved without the coordination and participant of production process.

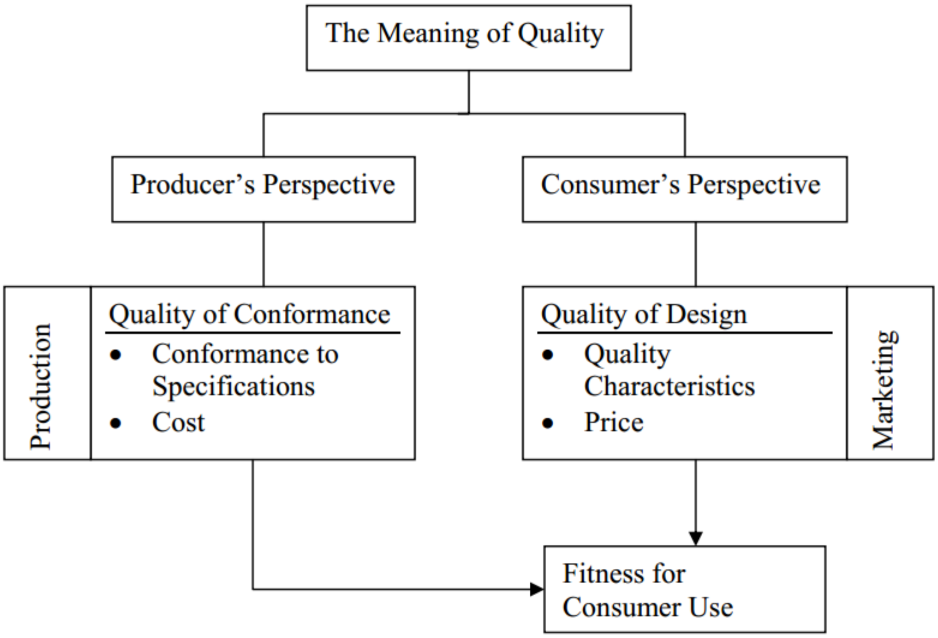



**Fig. 8** - Quality Definition from Producer and Customer Point of view

A more general and suited definition of quality is given by ISO-9000, that defines quality as *"The totality of features and characteristics of a product and service that bears on its ability to meet stated or implied needs"*.

## 2.2 Service Quality and Product Quality

As explained, fitness for consumer use depends on customer expectations. Analyzing the expectation concept, it is possible to deduce that the customer is satisfied when the product fulfills the characteristics promised by the seller.

A non-functional product creates an inconvenience for the customer, who will no longer be able to use it until it is repaired. For example, if our mobile's speaker does not work, the inconvenience consists in leaving the mobile to the assistance center for 2 or 3 weeks, thus loosing time.

However, a company can provide an excellent service quality, able to hide any product problem, meeting at the same time the customer expectations.

Brain X, Chen of the New York Times, wrote a piece arguing that traditional product reviews are broken insofar as they do not often consider the varying levels of customer service different companies provide. He wrote:

"The product evaluations neglect to mention the quality of company's customer service, which becomes the most important fact of all when problems or questions related to the product come up".

A benchmark example, considering tech products, is Apple.

Over the last decade, Apple has elevated customer service into a science. Apple retail store are everywhere. Across the globe, Apple has 454 retail stores. As result, Apple's infrastructure provides a welcome layer of convenience for users who need to bring a product in to be examined. This is more helpful than other companies provide, tech support via the phone. This means that Apple retail stores are only specialized in one thing: fixing Apple products [11]. Hence, a fast, efficient and comfortable repair service is provided, allowing to compensate any shortcomings in product design. The customer will be thus satisfied and delighted, even if a failure occurred.

On the other hand, the service provided highly depends on the type of product considered. Repairing or replacing a smartphone is relatively fast, economic, requires one or few people, and can also be done in a small environment.

It is possible to consider another type of product, addressed to a different customer with different uses.

An example of service quality benchmark in truck market is Volvo. A Truck customer has obviously different expectation respect to a mobile customer. The truck must be highly reliable and durable, zero stops or failure are needed, since repair a truck requires several days and thus loss of money for the transport company.

Volvo, developed a telematic roadside assistance, aimed to check, forecast, or eventually rapidly repair potential issues occurred on the vehicle.

The telematic Gateway technology connects the truck to the workshop, providing live information about the truck's engine, mileage, and fuel consumption. Technicians can also see diagnostic trouble codes and monitor the status of numerous components, like brake pads, clutch, battery and more. This live monitoring allows to reduce unplanned stops, and in case of repair is needed, the workshop is fully prepared, in order to fit the problem in the shortest time possible [12].

Second point, is the integration between smartphone and truck. Volvo Action Service on Call allows to talk with technicians in case of an unplanned stop. The operator knows the exact location, the chassis ID, and can pass on any diagnostic trouble codes, helping the driver, and in case, dispatch assistance to the truck location.

On the other hand, other companies invest more capital and put more effort on managing the product quality. In this case, the firm put more effort in build a quality system that involves all divisions, from engineering, to administration, aimed to design a robust, reliable and durable product.

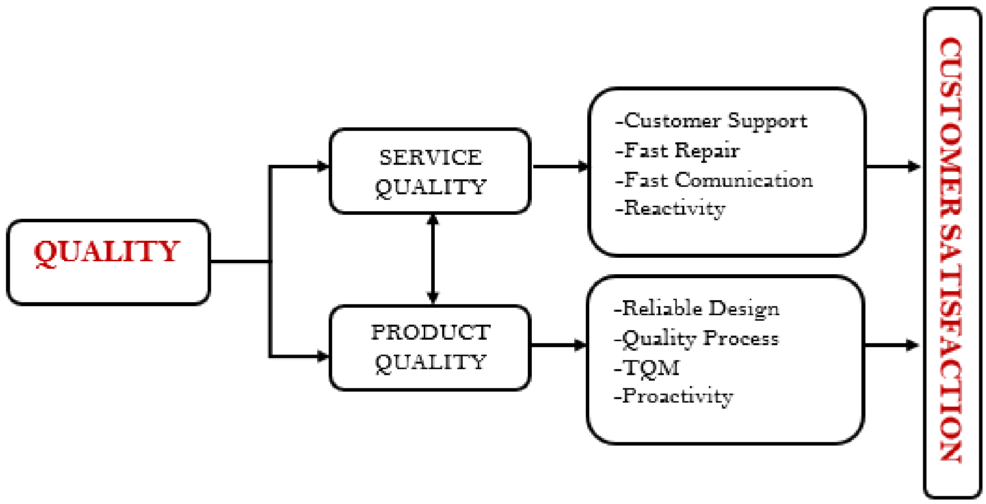



**Fig. 9 -** Service Quality and Product Quality Definition

Services are guaranteed, but have a lower weight on the perceived quality, since in this case the failure should never occur. There is not the necessity of service support, if the problem does not exist. It is more important to manage the product quality and performance proactively and preventively. Problem-solving and lesson learned extension are the key point to reach a potential zero-defect condition, satisfying and delighting the customer.

Hence, to achieve this total quality condition, specific methodologies and tools are needed, which will be discussed in the following paragraph.

## 2.3 Total Quality Management (TQM)

In late 1970s and early 1980s the developed countries of North America suffered economically in the face of stiff competition from Japan's ability to produce high-quality goods at competitive cost. For this reason, firms began reexamining the techniques of quality control invented over the past 50 years and how those techniques had been so successfully employed by the Japanese.

Quality Management began in the 1920s with the inspection, examining, and testing products, process and services against specified requirements to determine conformity. The early ISO 9000 quality definitions were targeted to documentation assurance. In providing evidence of correct processes and documentation, the assumption was made that good quality was achieved through correct documentation of what had been done. In the organizational practice, QM Systems were designed as (parallel) organization based on the role of quality agent (Hamschmidt 2001)

The quality can be seen as a company's strategy in terms of organization of internal production processes. The firm need to have a complete control of the quality, involving all the actors of the organization, becoming thus total.

The Total Quality Management consists basically in a organization-wide efforts to install and make permanent a climate in which an organization continuously improves its ability to deliver high-quality products and services to the customer. In other word, is a customer-oriented approach which uses statistical tools and techniques, such as PDCA mentioned before to continuously improve the procedures. The control of quality must be performed on the overall process and not only to the final product: if it is a quality process, also the final result will have a good quality. Also, the worker assume a paramount importance since he is now the responsible and can have a decisional autonomy.

Applying TQM guarantee survival of the firm in a world-class competition. It is thus an application of quantitative methods and human resource to improve all the process within a generic organization, that can be the plant of a company, can be the logistic or engineering division, or whatever field that needs improvements in organization and quality, that must be intended in its generic definition.

Quality should be monitored to identify problem immediately, using also statistical methods that can play a useful role.

TQM is a holistic approach to long-term success that views Continuous Improvement in all aspects of an organization as a journey and not as a short-term destination. It aims to a process and philosophy of achieving best possible outcomes from the inputs, by using them effectively and efficiently in order to deliver best value for the customer, while achieving long term objectives of the organization (Stenkamp 2009).

## 2.4 TQM tools and techniques

TQM as said before is a philosophy that involves everyone in an organization that has to put a continual effort to improve quality and achieve customer satisfaction.

It requires several tools and techniques in order to be correctly implemented. The experience has shown that some firms fail when they try to implement TQM, since the implementation cannot be successful without the use of suitable quality management methods and the application of appropriate tools. Using the wrong and redundant technique, cause waste of time and money. Furthermore, since there are lots of tools, a company should be able also to choose the correct one. In fact, some techniques are difficult to implement for time, cost, understanding, technology or resources available for a company.

The Seven Basic Tools of Quality is a designation of a fixed set of graphical techniques identified as being most helpful in troubleshooting issues related to quality. It is important to underline that they are Basic, since are suitable for people with little formal training, and they are used to solve the clear majority of quality-related issues.

| Tools \ Difficulty | *Time* | *Understanding* | *Terminology* | *Resources* | *Flexibility* | *Accuracy* |
|---|---|---|---|---|---|---|
| Cause and effect | | ✓ | | | ✓ | |
| Pareto | | | | | | |
| SPC | | ✓ | ✓ | ✓ | | |
| Quality costing | | ✓ | | | | ✓ |
| Departmental purpose analysis | | | | | ✓ | |
| Flow chart | | ✓ | | ✓ | | |
| FMEA | ✓ | | | ✓ | | |
| QFD | ✓ | | | ✓ | | |
| Check sheet | | | | | | |
| Histogram | | | ✓ | | | |
| Scatter | | | ✓ | | | |
| Graphs | | | ✓ | | ✓ | |

**Tab. II** – Main quality tools and their characteristics

**1. Pareto Diagram** - The pareto diagram is the most used and effective tool in order to evidence the common source of defects, or the highest occurring type of defect. It is a type of chart that contains both bars and line, where individual values are represented in descending order by bars, and cumulative total is represented by the line.

The purpose of Pareto is to highlight the most important factor among a typically large set of other factors. The Pareto Rule, called the 80/20 rule, says that the 80 percent of a generic activity is caused by the 20 percent of factors, and thus if a company concentrate its effort on this 20 percent of factors, it can attack the 80 percent of quality problems.

An example can be that the 80 percent of defects arise from the 20 percent of process issues, or the 20 percent of the sale force produces 80 percent of a company revenue, or furthermore the 80 percent of customer complaints arise from 20 percent of products or services, and so on.

The chart present two vertical axes, the one on the left showing frequency and the one on the right showing the cumulative percentage of frequency. The cumulative curve identifies few vital factors that warrant immediate managerial attention.

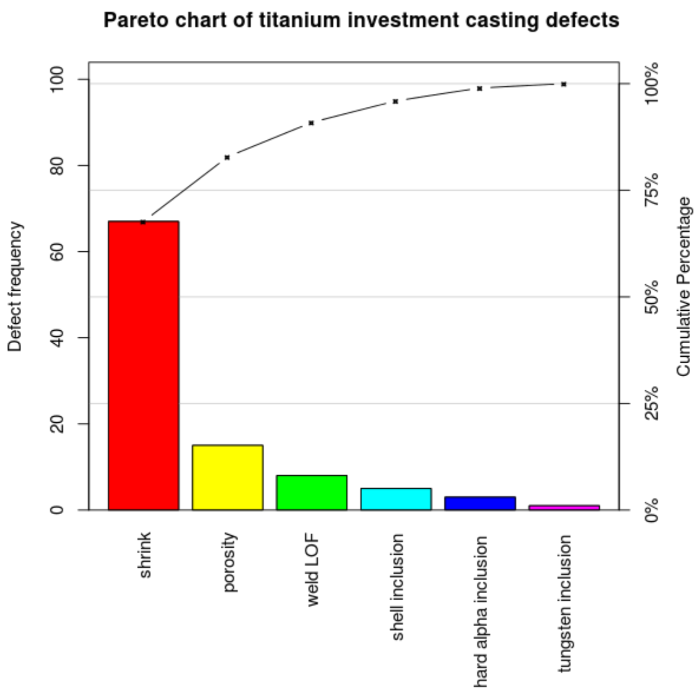



**Fig. 10** - Pareto Chart Example

**2. Graphs and Flow Diagram -** A Flowchart is a pictorial representation of the steps in a given process. The steps are presented graphically in a sequence, and can be used to describe an existing process in order to understand which are the weakest point or to propose a new one trying to forecast possible issues. The main question to answer while creating a flowchart is "what happen next", or "is there a decision made at this point".

Flowchart can be applied in each field in which there are a sequence of actions to be made and some decision to be taken, even in organizational tasks or manufacturing ones, in order to better understand which are the weakest part of a process involving different actions.

**3. Check Sheets** - It is a method to collect data related to quality in real time and fast way, exactly in the same location where the data is generated. The data can be qualitative or quantitative. The advantage of Check Sheets, even if may seem an easy tool, is to collect data in such a manner that it can be quickly and easily used and analyzed. Indeed, a preliminary output of the Check Sheet is a sort of histogram, that gives an idea of the number of concurrency and how data are distributed (for instance bell shape).

In quality control, check sheets can be used to quantify the defects by type, or by location or by cause, and then check the shape of the probability distribution of a process.

**Motor Assembly Check Sheet**

Name of Data Recorder: Lester B. Rapp

Location: Rochester, New York

Data Collection Dates: 1/17 - 1/23

| Defect Types/ Event Occurrence | Dates | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|
| | Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | |
| Supplied parts rusted | | ||||||||| | ||||| | |||| | || | | | 20 |
| Misaligned weld | | | ||| | | | || | | 5 |
| Improper test procedure | | | | | | | | 0 |
| Wrong part issued | | | | | || | | | | 3 |
| Film on parts | | | | | | | | 0 |
| Voids in casting | | | | |||| | || | | | 6 |
| Incorrect dimensions | | | | | | || | | 2 |
| Adhesive failure | | | | | | | | 0 |
| Masking insufficient | | | | | | | | | 1 |
| Spray failure | | | ||||| | | | | | 5 |
| TOTAL | | 10 | 13 | 10 | 5 | 4 | | |

**Fig. 11** - Check Sheet Example

**4. Cause and Effect Diagram -** The cause and Effect Diagram, called also Ishikawa, is a method for analyzing process dispersion. Its purpose is to relate cause and effect that can potentially contribute to a particular issue. It is a graphical explanation of the problem, and try to identify a root cause, by giving an image of the status of the problem, helping a group of people to discuss about it and eventually find some solution. It is also called fishbone diagram, and in order to identify and classify source of imperfection, all the potential causes are usually grouped into major categories.

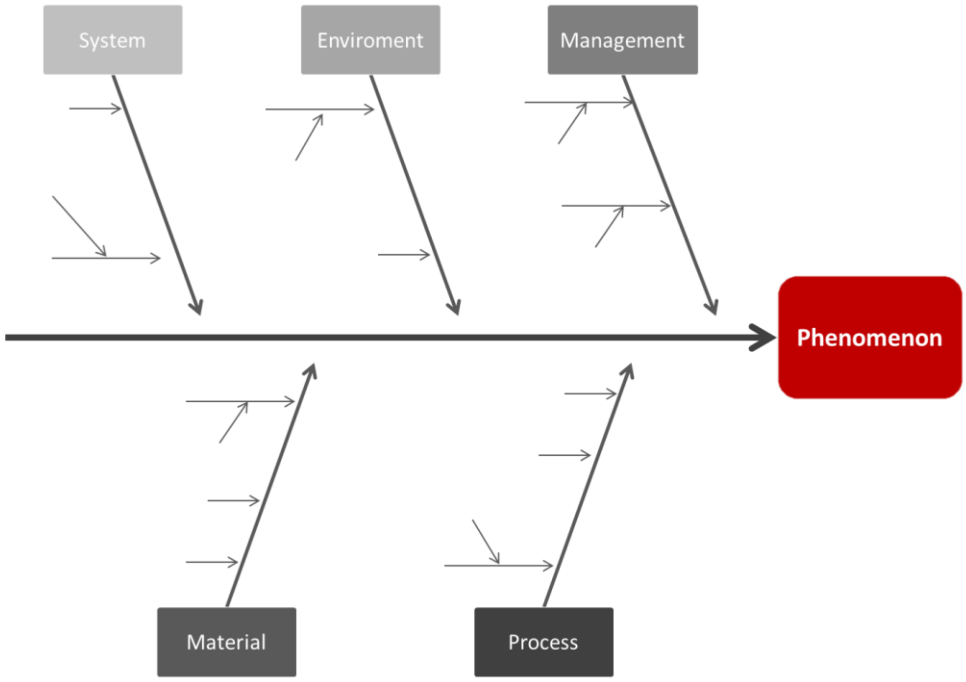



**Fig 12** - Cause and Effect Diagram (Ishikawa) example

As can be noticed from the image, the Ishikawa diagram can organize and display graphically the various theories about what the root causes of a problem may be, showing the relationship of various factors influencing a problem and allowing to focus attention on one specific issue or problem.

It was used firstly in manufacturing field to check and solve process issues, even if it this method is now spread and applied also in different division of a company.

**5. Scatter Diagram -** Scatter Diagram is a mathematical diagram used to plot pairs of data on a cartesian graph to find out relationship between the data sets. This tool is usually used after Ishikawa diagram is discussed, in order to determine objectively whether a particular cause and effect are related. Changing and input value (cause), the output value (effect) should be different, and from that is possible to find a linear, quadratic, cubic relationship between this two.

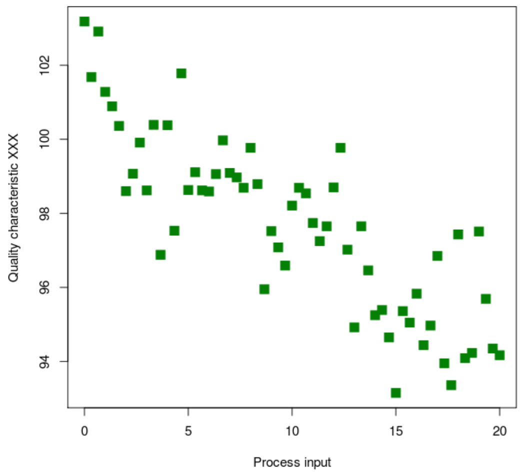



**Fig. 13** - Scatter Plot Example

For instance, if one suspect to have a defect (effect) related to plant temperature (cause), is possible to measure several times the temperature and check if the changing in specification of the product follow some kind of linear equation with the potential cause. The scatter plot is not used to investigate which is the root cause, such as Fishbone Diagram, but is to be considered a tool to check or confirm that the correct root cause has been identified.

**6. Control Chart** - It is a graph used to study how a certain phenomenon changes over time. It is a fundamental tool in quality, since it allows to continuously check the evolution and the quantity of defects over a certain period. The quality can be monitored and eventually, the trend can be predicted, in order to act in a proactive way, avoiding future increase of issue.

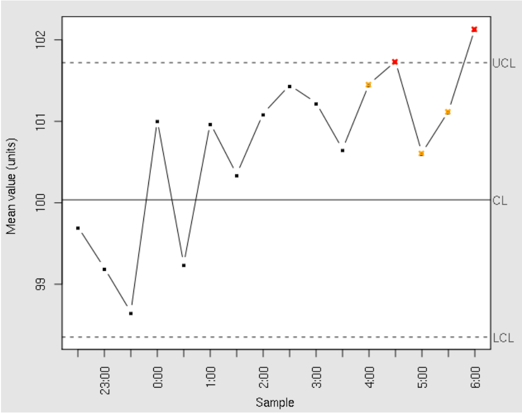



**Fig. 14 -** Control Chart Example

If the trend is stable in a certain period, no actions are needed, or can be performed some action in order to further reduce the quantity of defects.

If is noticed that there is an increase of the actual trend, future performance can be predicted, and some correction implemented.

An example can be the quantity of defects in vehicles built each month. The trend of defects can increase after a certain point. Thus, the trouble shooting team, start to investigate the potential root cause searching some possible issue in that specific month, evaluating the boundary condition and eventually the modification to the process that were implemented in that month.

After the checking phase, a solution is implemented, and the effectiveness of this solution is evaluated and confirmed if the defects trend start to drop again.

**7. Histogram -** The Histogram is the more simple and effective method used in quality control. It is a graphical representation of a distribution of numerical data. It basically shows how often each different defect in a set of data occur. An Histogram is different from a bar chart, since it shows the frequency distribution, giving thus an image about the kind of distribution, if it is normal or not. It is used for continuous data, where bins represent ranges of data (no gap between bars), while bar chart is a plot of categorical variables.

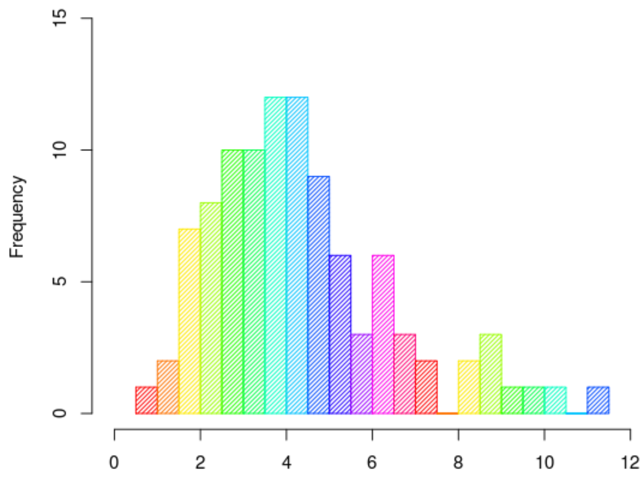



**Fig. 15** - Histogram Example

Dealing with quality, shows the probability that has a certain defect to occur, providing a schematic and straight idea of the probability of a certain product to be out of specifications.

## 2.5 Problem Solving with Kaizen Tools

The 7 TQM tools, are of paramount importance during troubleshooting phase, to have a clear idea about the whole situation of the problem, however is needed a logic sequence and standardization to apply them when necessary and in the correct order, avoiding thus waste of time and money.

The problem-solving phase can be defined as a process that apply generic or ad hoc methods, in an orderly manner, for finding solutions to problems.

Kaizen philosophy to problem solving suggest that a company must have the capability to periodically conduct self-analysis and explore ways to continuously learn how to improve the development process. This is a lean principle aimed to solve each kind of waste (money, time) based on the proactive idea that is important to solve problems but is more important to investigate and find problems also when they do not come out, and everything apparently is within standards.

Kaizen thus suggest investigating and solve problem as they arise, implementing standards that serve as baselines and targets to measure the realized improvements.

The proposed model recalls the PDCA scheme (chapt. 1) and is composed by 4 phases:

- Reflective Practices
- Double-Loop Learning
- Analysis Technique
- Policies and Standards

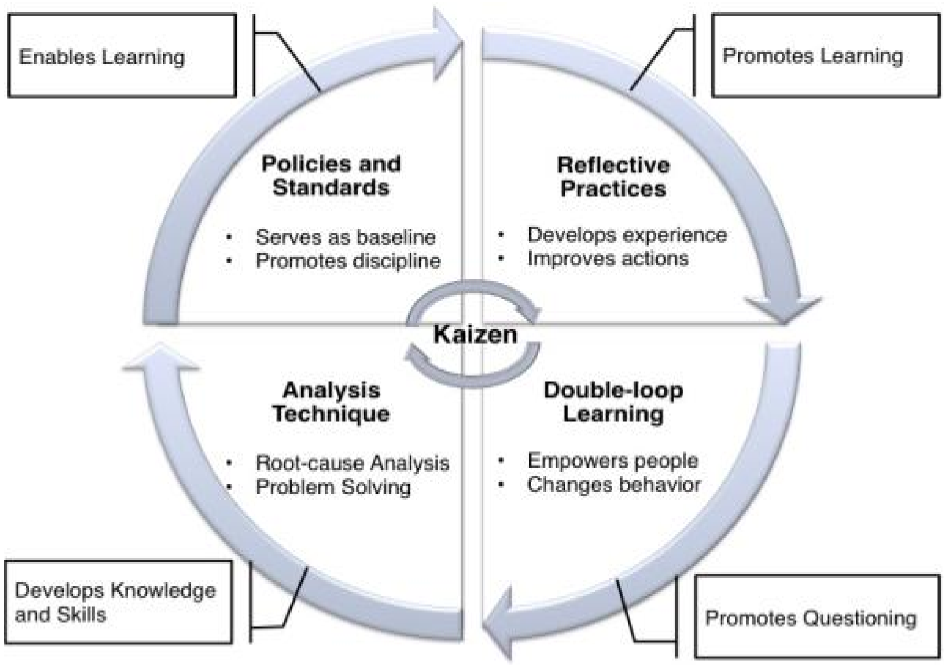



**Fig. 16** – Kaizen implementation

*Policies and standard* represents the best way to know how the work should be accomplished at any given instant, even if they should be flexible enough to be altered once a better way is identified. In fact, *Reflective practices* allow to bring knowledge from past to present activities, resulting in higher (or sometimes lower) levels of organizational effectiveness. For this reason, standards need a certain flexibility, and should be continuously monitored in order to apply some modification if a certain non-efficiency is revealed. Each standard, or methodology that is putted in field in trouble shooting phase must not be implemented only in a schematic way, as a set of steps that for sure bring to the solution of the problem: a *Double-Loop Learning* phase is required. In this phase, an individual must consider the reason why a problem exists, trying not only to identify the problem, but also find the underlying reason for occurrence. After that, the *Analysis Technique* phase can start, that is the core of the problem-solving process, using an important tool called 5 Whys [13].

## 2.6 5 Whys method

The 5 Whys is a root-cause analysis technique that was devised by Toyota during the evolution of the lean production system. Taiichi Ohno, the architect of TPS in the 1950s describes the method in his book as "The basis of Toyota's scientific approach [...] by repeating why five times, the nature of the problem as well as its solution becomes clear."

It is commonly used in lean enterprises. In the beginning, it was used only in manufacturing issues, but later this methodology was spread and used almost for anything: development mistakes, site outages, marketing program failures, internal missed schedules, logistic or quality problem, as provides a factual-based approach to identify the causal link between the problems and their root causes. It also gives the ability to question the course of action while it is being implemented, which realizes the objectives of reflection-in-action.

It's important to note that the purpose of the 5 whys is not to place blame, but rather to uncover the root cause of why something unexpected occurred. Additionally, it helps a team to create small, incremental steps so that the same issue does not happen again.

The primary goal of the technique is to determine the root cause of a defect or problem by repeating the question "why?", and each answer forms the basis of the next question. Indeed, by repeatedly asking "Why?", it is possible to peel away layers of issues and symptoms that can lead to the root cause.

**Example -** *The laptop do not switch on*

| **5 Why Question Table** | | | |
|---|---|---|---|
| **Team Members:**<br>**Date:** | | | |
| **Problem Statement**: While you started to work, your pc suddenly shut off | | | |
| **Recommended Solution:** Prevent the dog from coming into contact with the charger | | | |
| **Why Question** | **Answer** | **Evidence** | **Solution** |
| 1. **Why** the laptop shut off? | Because there is lack of electricity | Screen become black | |
| **2. Why** there is lack of electricity? | Because the charger is not working | Laptop do not switch on also if ON/OFF button is pressed | Try to disconnect and reconnect the power plug |
| **3. Why** the charger is not working? | Because the cable topping is cut off | Also with charger inserted, the laptop do not switch on | Fix it or buy another charger |
| **4. Why** the cable topping is cut off? | Because my dog bites the cable | The trimming is detached and the copper cables are outside | Close the studio door when there is nobody at home |
| **5. Why** the dog bites the cable? | Because I forgot the charger on the floor | Has forgot the charger on the floor many other times | Remember to leave the charger on the desk |

**Tab. III** – 5 Whys Question table

In order to use the 5 whys method in a correct way, is important to follow 4 basic steps:

1. Assemble a Team;
2. Define the problem;
3. Ask Why 5 times;
4. Stop or Loop back.

These steps are of paramount importance to correctly fill the 5 Why Question Table. Above (Tab. III), a brief example of how to use this methodology [14].

The table shows two additional columns. The Evidence one is a sort of confirmation, an evidence that the specific issue is happened, instead the solution one tries to give a temporary solution to that problem to understand if is useful or not go ahead with the next why. However, is important to underline that the 5 Whys uses "counter-measures", rather than solutions. A counter-measure is an action or set of actions that seeks to prevent the problem arising again, while a solution may just seek to deal with the symptom. As such, counter-measures are more robust, and will more likely prevent the problem from recurring [15].

A drawback of the 5Whys tool is that must be used in a careful way when tracking complex or critical problems. Indeed, 5Whys can lead to pursue a single track, or a small number of tracks, when there could be multiple causes.

In our example, a second path to follow could be that the computer is shut off since the inner laptop plug is broken. Thus, in that case, changing the charger is not the solution to the problem. This means that the 5Whys analysis sometimes is not able to explore all the space of possible root cause to a particular issue. In such cases, a wider-ranging method such as Cause and Effect Analysis or Failure Mode and Effects Analysis should be more effective.

However, this tool's simplicity gives it great flexibility, combines well with other methods and techniques, and can often direct quickly to the root cause of a problem.

## 2.7 5W and 1H for Phenomenon Description

The 5Whys analysis is used to find out the root cause of a specific issue, but this tool do not specify the boundary condition in which the phenomenon occurred. In fact, an overview of the condition, the people, the time, the location in which the problem is verified is necessary. In order to cluster all these information, the 5W and 1H method is used.

It is a simple set of question framings, What, Where, When, Why, Who and How, and answer to that questions in a simple and effective way will provide a structured and clustered thinking process to describe the phenomenon.

| | | |
|---|---|---|
| **What** | **What** did happen?<br>What was not working? | The laptop switch off<br>The charger was broken |
| **Where** | **Where** it was noticed? | The breakage was on the exterior trimming of the charger's cable |
| **When** | **When** the problem occour?<br>Did it occour sistematically? | The problem was noticed using the Laptop |
| **Who** | **Who** was responsable of the problem? | The dog |
| **How** | **How** the breackage occurred? | The dog bit the cable |
| **Why** | **Why** the problem is verified? | Because the charger was on the floor |

**Tab. IV** – 5W and 1 H Table

Indeed, sometimes during the identification and the description of a problem, some information could not be taken into account, leading thus to a dispersion of information that can be avoided only using a schematic method.

In troubleshooting and problem identification phase, the question to answer are the following:

- *What* Changed respect to normal use? What is the magnitude of this Change?
- *When* was it noticed? When did it happen?
- *Where* did the issue appear?
- *Who* noticed the problem?
- *Why* did the change occur? Why did the problem appear?
- *How* did it happen? In which way did it occur?

Considering the laptop shut off example, examined in the previous paragraph, the above table (Tab. IV) can be filled.

# CHAPTER 3

## WORLD CLASS CONCEPT

## 3.1 World Class Manufacturing

As mentioned in the first chapter, in the past decades the world has witnessed the emergence of effective forces which seek to reshape the economic and organizational communities, changing thus the way to make business [16]. The globalization and the requirement to satisfy a market that expecting more quality than quantity, needed the development of efficient service quality, new technology, new processes, and thus a completely new way of thinking and acting.

Innovation is a necessary process for the continuous changes in order to contribute to economic growth in the manufacturing industry, especially to compete in the global market [17] .

In a more practical view, considering the profit equation:

$$Profit = Selling\ Price - Cost$$

is easy to understand that the profit is the only thing that keep a company alive. If in the past was possible increase the profit either with high cost of production, material, logistic, administration, and ether wastes, since the purchased quantity was high, modern firms are dealing with a selling price reduction determined by a saturated marketplace. In other words, profitability can only be realized through reduction of costs, or an increase of selling price by producing a higher quality product. Therefore, product quality and cost reduction are the two fundamental aspects in which a firm must put effort in order to compete in a global market, being thus a world class company.

There is no universally recognized definition of World Class Manufacturing (WCM) [18] . Schonberger coined the term “World Class Manufacturing” to cover the many techniques and technologies designed to enable a company to match its best competitors.

Hayes and Wheelwright in a second moment described WCM as a set of practices, implying that the use of best practices would lead to superior performance [19].

However, there is not a general vision and definition of WCM, implying that this set of rule, methods and standards strictly depends on the firm's nature and of its productive resources. It is thus not possible to use a specific single tool to achieve world-class performance, but this approach demands a radical change in mindsets.

Schonberger argued that WCM affect almost every aspect of production, and there are four specific attributes which should always be included in WCM implementations, that are Total Quality Management, Just in Time manufacturing techniques, management of the work force and flexible approaches.

The emphasis on *quality* is achieved by the goal of zero defects, resulting in the elimination of buffers such as inventories of semi-manufactured goods. Thus, manufacturing become more susceptible to interruptions and quality problem in a single operation can bring the entire production to halt.

A *production line* requires thus a simplification of production and organization, in combination with new production technology, facilitating throughput times. The WCM transforms production from a functional to a flow-based layout [20]. In the functional layout, machines with similar functions are located in groups, instead in a flow-based system machines with dissimilar functions are collected in group. The former demands less material handling activities and the flow of production will be less complicated than in a functional layout.

The *Management of Work-Force* suggested by WCM is based on the Specialization.
For instance, the quality checking task is addressed to manpower specialized. The organization will become horizontal rather than vertical: responsibility and authority won't belong to a single manager that will control a vast area with a

huge number of tasks and target, but will be delegated to relatively small, more specialized and independent teams [21].

Thus, the WCM is a continuous improvement program that, using standards and specific tools, is able to radically change the production process till the achievement of a degree of excellence that is recognized and certified by the best manufacturing firms in the world (World Class). As the Lean Production, it aims to maximize the added value of the production process, eliminating each kind of waste, and integrating all the work force in the whole organization of the firm, introducing them to a lean and continuous improvement mentality.

The three-key concept are:

- Added Value
- Loose
- Waste

The WCM targets can be obtained:

- Implementing specific methods in technical and managerial pillars;
- Applying and diffusing tools;
- Changing thinking behavior of all the company.

Using in a correct way these factors, is possible to reach the "Zero Level", that can be easily summarized as follow:

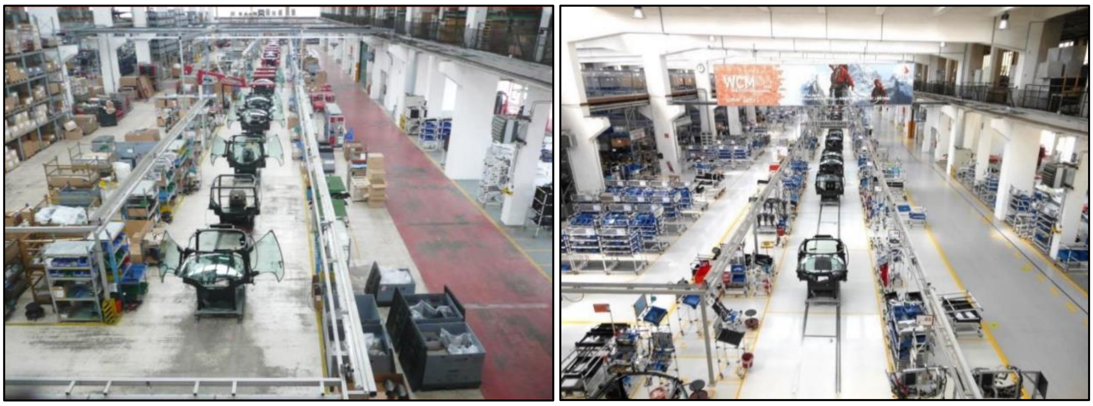
- ZERO customer dissatisfaction
- ZERO misalignment
- ZERO bureaucracy
- ZERO wastes
- ZERO work that do not creates added value
- ZERO stops
- ZERO opportunity loosed
- ZERO information loosed

However, WCM has some difference respect to the Lean concept. Indeed, it is structured approach, based on steps and pillars, giving a methodology to the planning and organizational phases. Another important difference, is the measurability. Indeed, WCM imposes some rules to measure the efficiency of each firm's division, even the administrative ones, in order to quantify in each moment, the performance of the whole company.

There are two indicators: key performance indicators (KPI) that measure the classical productive performances, and the key activity indicators (KAI), that measure the action needed to reach a defined target

The level of performance is checked by a system of internal and external audit. Internal audit is a self-evaluation system, planned and implemented by the pillar managers. Indeed, the external audit are delegated by the World Class Manufacturing Association.

The following pictures show a comparison before and after the WCM introduction in CNHi Saint Valentin Plant (Austria).



a) b)

**Fig. 17 –** CNHi Plant: **a)** before WCM implementation
**b)** After WCM implementation

## 3.2 World Class Pillars

The world class methodology is articulated in ten technical pillars, based on ten managerial pillars.

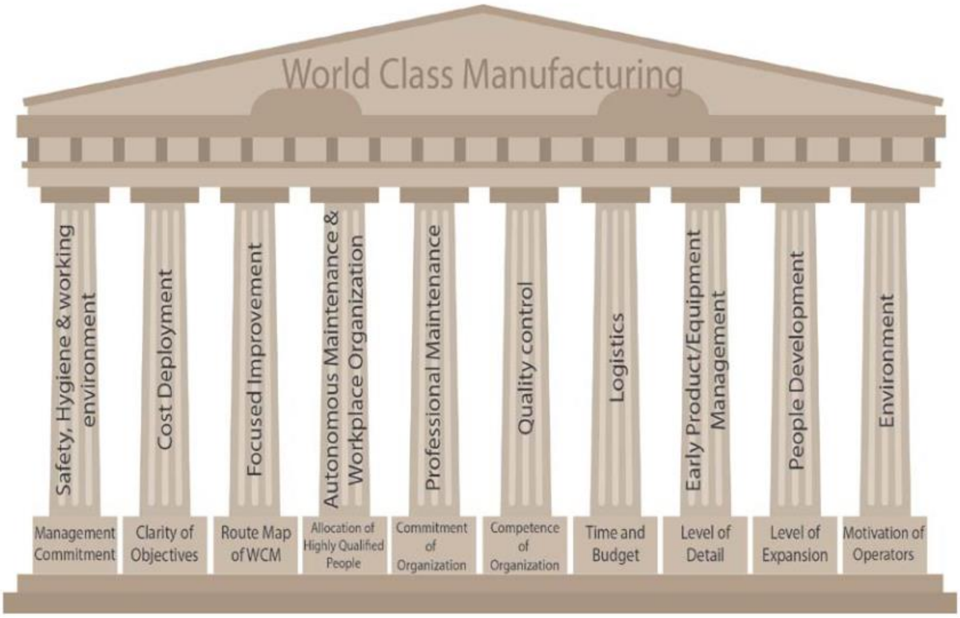



**Fig. 18** - WCM house and pillars

Basically, a pillar is a team composed by people working in a specific area focusing their work on a common topic to reach a defined technical target.

Each pillar represents a field, a company division in which the firm must focus and put effort to increase competences and reach a World Class status.

Differently from technical pillars, managerial pillars represent a reference point for managers and plant directors. Indeed, they suggest that to reach a technical excellence level, is also important to focus on managerial elements, such as organization, planning, leadership and motivation. Thus, the world class level is not only reachable with innovative technical solutions, but also by changing the organizational structure.

In order to achieve skills and competencies in a specific pillar, seven steps need to be implemented, starting from basic ones, arriving to the top one that represents the state of excellence.

The steps are the fundamental characteristic of the WCM, and represent the macro-activity to be performed to reach the excellence level. They are divided in three sub-levels according to the depth in which the problem is deal: reactive level, preventive level and proactive level.

In the following table, a brief explanation of the role of each pillar, highlighting target and expected results.

| PILLAR | TARGET | EXPECTED RESULTS |
|---|---|---|
| **Safety** | • Reduce number of accidents<br>• Envelop prevention culture<br>• Increase workplace ergonomic | • Zero condition for potential accident<br>• Increasing Workplace quality |
| **Cost Deployment** | • Liminate potential economical wastes<br>• Quantify economical benefits | • Capacity of eliminate sources of losses<br>• High competence in using methods to eliminate wastes |
| **Focused Improvement** | • Delate non-added value activities<br>• Eliminate inefficiencies of the process<br>• Problem Solving competencies | • Wastes Reduction<br>• Continuous improvement mentality |
| **Autonomous Maintenance** | • Stop accelerated deterioration<br>• Increase product quality<br>• Develop product and plant competencies | • Increase of plant efficiency<br>• Increase motivation |
| **Workplace Organization** | • Eliminate non-added value activities<br>• Increase worker's involvement<br>• Increase productivity | • Increased product quality<br>• Increased work cycle efficiency |
| **Professional Manteinance** | • Diffuse failure analysis methodology<br>• Facilitate collaboration between workers and maintainers | • Increased machine efficiency<br>• Machine Failure reduction<br>• Planned maintenance |

| | | |
|---|---|---|
| **Quality Control** | • High quality with minimum cost<br>• Define optimal condition to avoid defects<br>• Keep product in optimal specification | • Increased customer satisfaction<br>• Increased product quality |
| **Logistic - Customer Service** | • Create material flux with suppliers<br>• Reduce stocks<br>• Minimize handling | • Timely order processing<br>• Increased Logistic competences<br>• Fast and efficient delivery |
| **Early Equipment Management** | • Design efficient plant<br>• Reduce plant lifecycle cost<br>• Guarantee fast and stable start-up | • Autonomous mantainance easy to perform<br>• Prevent failure |
| **People Development** | • Develop professionality<br>• Appropriate skills for each work role | • Direct Implementation of quality control<br>• Autonomous maintainance implementation |
| **Enviroment** | • Develop enviromental prevention culture<br>• Increase reciclability | • Energy consumption reduction<br>• Reduced Enviromental impact<br>• Reduced Wastes |

**Tab. V** – World Class Manufacturing pillars

Is possible to notice that the aim of WCM is not only eliminate losses inside a process, but also create an internal structure able to eliminate waste sources in a continuous way. This target can be achieved involving all the actors, that must cooperate, but also work in an autonomous way, finding and eliminating wastes sources. This practice is performed step by step, thus increasing in an incremental way the number of activity that the single workers is able to perform autonomously. Once that the activity of a single step is consolidated, the method is extended to neighboring areas, and after 7 steps, to the whole plant.

Each step efficiency and progress can be monitored implementing a suited KAI and KPI indicator. The latter represents the imposed target, instead the former suggest the progress state respect to the imposed objective.

## 3.3 Cost Deployment Pillar

The World Class level, can be achieved not only developing each pillar till a premium class state, but is necessary a certain integration between each pillar.

Cost Deployment can be considered a transversal pillar, since each activity carried out in a company, from manufacturing to administration, is driven by analysis activities and possible cost reduction.

Cost Deployment (CD) plays the key role in identifying, analyzing and translating waste and losses to monetary units [22] , allowing management to apply an effective improvement project to attack the most significant causes of loss and achieve the highest level of company growth. The aim of CD is not only understanding if there could be savings somewhere, but also to try to identify wastes through cost, and thus planning actions in term of priority.

It is basically a method for establish a cost reduction program, performed in a scientific and systematic way, in order to find useless costs resulting from losses and wastes, and try to reduce them implementing targeted projects [23].

First objective of this projects is to individuate the costs coming from non-added value activities.

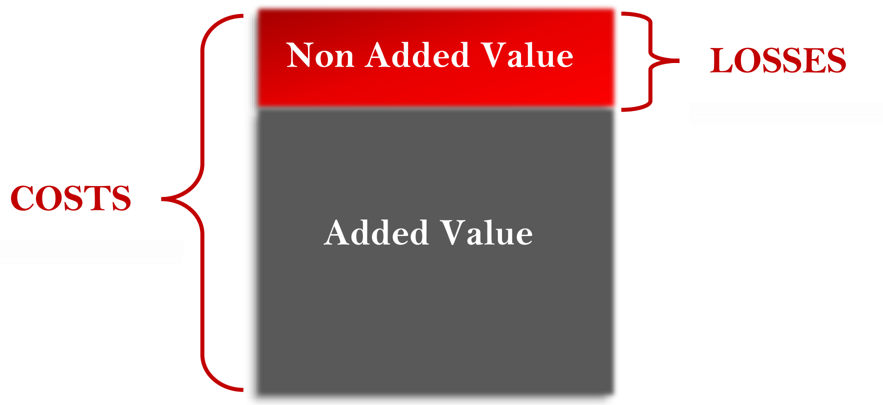



**Fig. 19 -** Non-Added Value Costs

Once the waste sources are individuated, the CD cooperates with others pillars to develop projects aimed to eliminate the losses root causes. Indeed, CD is able to find the waste sources, but cannot attack the cause autonomously. From that arise the "transversality" of this pillar.

The seven steps to reach the World Class Level of this pillar are:

1. Identify total costs, establish a reduction cost target and allocate the costs to single process that generate them;
2. Identify wastes and losses in a qualitative way and then in a quantitative way;
3. Identify link between losses elimination and the related cost reduction;
4. Translate wastes in costs;
5. Identify methods and tools to attack costs;
6. Identify projects to attack costs and estimate the potential cost reduction;
7. Check and evaluate the status of projects, identify the next year budget applying a follow up methodology by restarting from step 5.


**Fig. 20** - Seven Steps for World Class Level with PDCA

The transition from one step to the other one is possible thanks to the rigorous implementation of the Kaizen and PDCA method, highlighted in chapter 2.

## 3.3 Quality Control Pillar

This pillar is one of the most important, and its development starts from the Cost Deployment definition, since each activity carried out in a company is driven by the only target to reduce to minimum costs. The main objective is reach customer satisfaction reducing costs, managing production system and increasing the skills of the quality manager. World class firms are aware of the importance of quality and how much it can affect the cost and thus income. Quality check are non-added value actions: they are a useless phase of the production process and thus they must be avoided defining qualitative standards that must be respected either in product and process design. Quality check do not add any feature to the final product. The target of this pillar is to reduce the importance of final check by preventing process defects, carrying out a control system a priori rather than a posteriori.

For this pillar, WCM provides structured and effective tools to improve results. The point is however that quality problems usually do not have a root cause easily identifiable, i.e. it is not possible to identify a cause of the problem quickly. For every problem there must be a different approach and targeted tools.

WCM offers guidelines, using the following steps for quality improvement:

- *Defects Deployment* to analyze the origins of non-conformity (QA Matrix);
- *Condition Definition* useful to reach the required quality (QM Matrix);
- *Construction, training and management* of quality improvement teams;
- *Standard Operating Procedure* Definition;
- *Prevention Cycles* Definition;
- *Lesson Learned* definition, implementation and maintenance

# CHAPTER 4

## WORLD CLASS PROBLEM SOLVING METHODOLOGY

## 4.1 Introduction

During the first decades after World War II, well-being and industrialization led to a growth in industrial production. Each product was created in huge quantities to meet the needs of each customer. The chronic quality issues were very common, but in absence of directive they were solved using brute-force approach.

The Brute-Force approach to solve quality problems simply consisted in solving individual problems using only methods deriving from the logic of each individual worker, not considering quality problems from a global point of view.

Quality issues were considered an impossible evil to eliminate and the methodology for solving these problems was to check randomly if the pieces were out of specification, and if necessary fix them.

In this chapter some philosophies and methodologies that a firm must implement to reach a World Class Quality level will be discussed.

## 4.2 Four Stages of Quality - Management

Before the discussion of the methodology for solving chronic quality problems, it is necessary to establish the infrastructure of a comprehensive quality process that a company must construct in order to aspire to World Class Quality.

There are basically four stages for quality, from a primitive Stage 1 to a world class stage 4.


**Fig. 21** - Organization World Class steps

A company in Stage 1, called Stage of innocence, is not aware of the importance of quality, from an economical point of view, but on the contrary it is seen as an extra cost to be avoided. In the stage 2, called awakening stage, a company recognizes the importance of quality but is thrashing around without a specific and studied plan. Stage 3, called the stage of commitment and implementation, the company start to plan and implement quality tools. In Stage 4, the firm is become a World Class company and is a benchmark for competitors.

The management of quality process is the key to success. Indeed, is possible to say that the 85 percent of quality problems are the responsibility of management, instead only 15 percent are the responsibility of the worker [24]. Quality starts and ends with management.

In stage 1 management looks upon quality as a necessary evil, a company's cross to bear.

In stage 2 it admits that quality is important but costs money. It believes that high quality is in contrast to low cost. This is one of the most common manager's error. It is obviously easier and momentarily inexpensive not to invest in the overall quality process, but limit to only checks at the end of the line if a product is out of spec or not.

The real problem arises when a certain defect becomes epidemic and the simple end of line check is no longer enough to guarantee the integrity of the final product. In this case, the losses are significantly higher than the costs for upgrade the global quality system.

Thus, in stage 3, the company finally recognizes that quality is not negative, and a consistent quality system should be implemented also from customer and suppliers. The company is aware that the Return on Investments (ROI) will be high if a reliable quality system is implemented. The quality is the only variable to play with, is the only factor that can be controlled, on which is possible to work, it is an input to give to the process. Profits and ROI cannot be worked on, they are results, output. Quality can be worked on, and in Stage 3 becomes an absolute economic imperative.

In Stage 4, Management elevates quality to a superordinate value. Prevention of quality problems becomes a way of life in product and process design, in manufacturing systems and with suppliers.

In other words, from a practical point of view, Stage 1 is characterized by inspection and testing, sorting and screening, which are brute force methods to achieve quality. Stage 2 develops corrective methods with problem solving teams; Ford's 8-D program is an example of a correction system. In Stage 3, management devotes its resources to problem prevention, along with support and follow-up of preventive disciplines. Stage 4, is called "proactive" stage.

## 4.3 Four Stages of Quality – Organization

In the area of organization, Stage 1 employs the usual bureaucratic pattern called vertical management, where communications tend to follow up and down, from and to the boss, rather than horizontally between departments. In Stage 2, there is a functional organization, even if this structure can give some confusion to a person having "two bosses".

Stage 3 the team concept is introduced. Under the guidance of a top management quality steering committee, diagnostic, interdisciplinary teams are established to so solve major quality problems. In this stage, responsibility for quality gets deployed to line functions, to engineering, manufacturing, and purchasing.

In stage 4, the team concept, becomes pervasive throughout the company and institutionalized within the framework of a focused factory. In this stage, quality becomes so pervasive that all employees enthusiastically accept responsibility for quality in their own areas.

Contrary to stage 3, in which the quality assurance department is composed by an important number of people who responds to a top


**Fig. 22** - Quality Steps to reach world class level

manager, in stage 4 the quality assurance team is composed by 2-3 people who reports directly information to the CEO. The mission of this team is not to blow the quality whistle but to help all employees accept their quality responsibility and reach their full quality potential.

## 4.4 4M Factors

Starting from the base ideas of the Quality Control Pillar, the quality characteristics of a product strictly depends on 4 important factors: Material, Method, Manpower and Machine. These 4 factors are the only to work on in order to reach a 0 defects status.

Issues related to machine can be solved adopting the 7 steps for machine maintenance explained in the WCM pillar, with the objective to define operative standards that can bring to a 0-defect condition.

Man, Method, Material problem are instead attacked by problem solving tools, applying PDCA problem solving formula.

The countermeasure to be taken into account are different, according to the problem-solving phase the company is facing:

- Reactive: are actions taken after that an event has taken place;
- Preventive: avoid similar problem under similar condition, extending countermeasures in other areas;
- Proactive: based on theoretical risk analysis, proper countermeasures to avoid a serious event to occur are taken.


**Fig. 23** - Different way to face an issue

In each of this action type, is possible to identify some fundamental tool to be applied to carry out the problem-solving phase in a schematic and structured way, reaching and implementing finally a lesson learned that will be translated into a standard for the whole company.

## 4.5 ISO 9001 Standards

There are a set of standards aimed to evolving the quality system of a company, taking it towards the achievement of the World Class Quality status. These standards can be implemented using TQM and Kaizen tools explained above.

The ISO 9000 family of quality management systems standards are some tools and techniques to help organizations, ensuring that they meet the needs of customers while regulating requirements related to a product or a service. They include the seven quality management principles upon which the family of standards is based.

ISO 9001 sets out the criteria for a quality management system and can be used by a small or large organization, regardless the field of activity. The standard is based on a number of quality management principles, including customer focus, top management, process approach and continual improvement.

Applying ISO 9001 the organization must continuously improve its quality management system, A company that choose to apply ISO 9001 agrees to completely redesign its quality system, basing each activity in quality performance. This standard is obviously tailored to the type of company taken in consideration.

The main macro areas considered are:

- Management
- Planning
- Marketing
- Design
- Sales
- Supplying
- Production
- Assistance (Post-Sales)

The whole company is quality oriented. Each activity carried out is based on achieving the highest possible quality. ISO 9001 represents the starting point for the achievement of a World Class Quality Status.

## 4.6 Problem Solving Steps

Problem solving is the heart of problem management within a company. What makes it so important and sometimes difficult to be applied using logic alone is the vastness of possible root-causes that can be linked to a single problem. In the automotive sector, a problem such as an excessive vibration of the steering wheel leading to the breaking of the steering column can be caused by an infinity of small problems.

A batch of fractured material may have been received by the supplier, or the operator was not able to properly anchor the steering column with the rack, or simply the end customer has traveled over gravel roads using inappropriately the vehicle.

Therefore, using personal logic in the development of a problem-solving may be inappropriate, sometimes leading to a waste of time and therefore money.

Defective pieces could continue to be produced while desperately searching for the root-cause of the problem and therefore a countermeasure, losing a large amount of money.

For this reason, it is important to give a schematic approach to each phase of problem solving.

First, it is important to **identify the problem** from the customer's point of view. This problem consists of an "out of spec" condition, and it is of fundamental importance to detect if and how many cases there were of the same problem.

Subsequently the **phenomenon** must be described. Phenomenon is just the condition that produces the problem.

Therefore, after having described the phenomenon it is possible to identify a **defect**, that is a physical condition outside the designated specifications. The defect could be, as in the previous example, a crack on the steering column. The defect produces the problem through the phenomenon.

Finally, it is possible to arrive at the description of the **root cause**, that is the cause that triggers the final problem. The Root Cause is addressable to one of the 4M, and is the only element on which is possible to work to solve the problem.

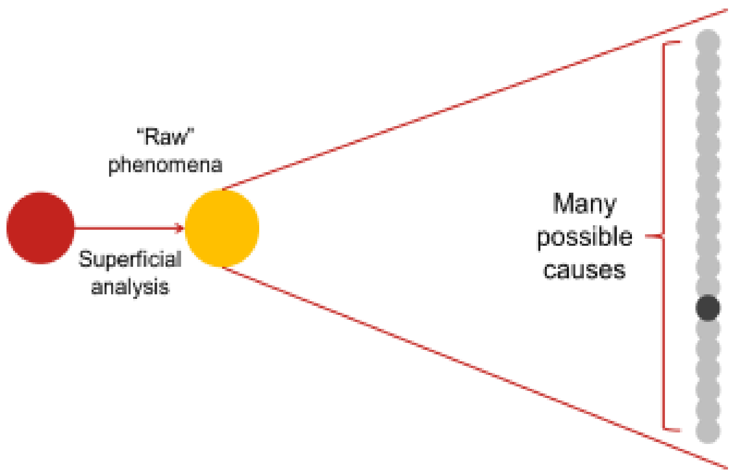



**Fig. 24** - From phenomenon to root cause graphical description

As mentioned before, it is often difficult to understand the root causes of a problem, since a single root cause can create multiple problems, and multiple root causes can cause a single problem.


**Fig. 25-** From Problem to Root Cause - User point of view

Fig. 25 shows how the user perceive the problem. A different situation from the standard condition is noticed (problem). The problem is evidenced by a certain phenomenon. The defect instead, is a physical condition in which something is wrong. The defect produces the problem through the phenomenon. At the end, the root cause is an initiating cause or either condition or causal chain that leads to a defect.


**Fig. 26-** Issue Timeline

Fig.26 shows the problem's timeline point of view. A certain root cause leads to a defect that manifests itself through a phenomenon perceived by the customer as a problem. Obviously at the end of these steps, an action must be implemented. The action traces the 4 steps described, until the root cause is identified. It is important to follow the steps backwards to avoid implementing actions on the wrong root cause.

Thus, after identifying root causes, a corrective action must be implemented to eliminate the problem. The countermeasure to be applied can be a containment action or a definitive action. Since modifying a component can be very expensive and can sometimes take a long time, it is important to try to "limit" the damage with a containment action, that is a corrective action that does not eliminate the problem but decreases its intensity.

The 4 steps mentioned can refer to the PDCA process.

During the plan phase, the topic is selected, considering the problem to be attacked. Starting from the current condition, targets are set, which usually refer to the total elimination of the problem. These targets will then develop into a planning activity, which involves the analysis of defects and the study of occurrences. It is important to analyze every defect found in the past, and to understand if this defect can be related to the problem taken into consideration.

As can be shown from the following scheme, PDCA process is divided into 7 steps, taking this concept from WCM. Last 3 steps are referred to the establishment of optimal condition.

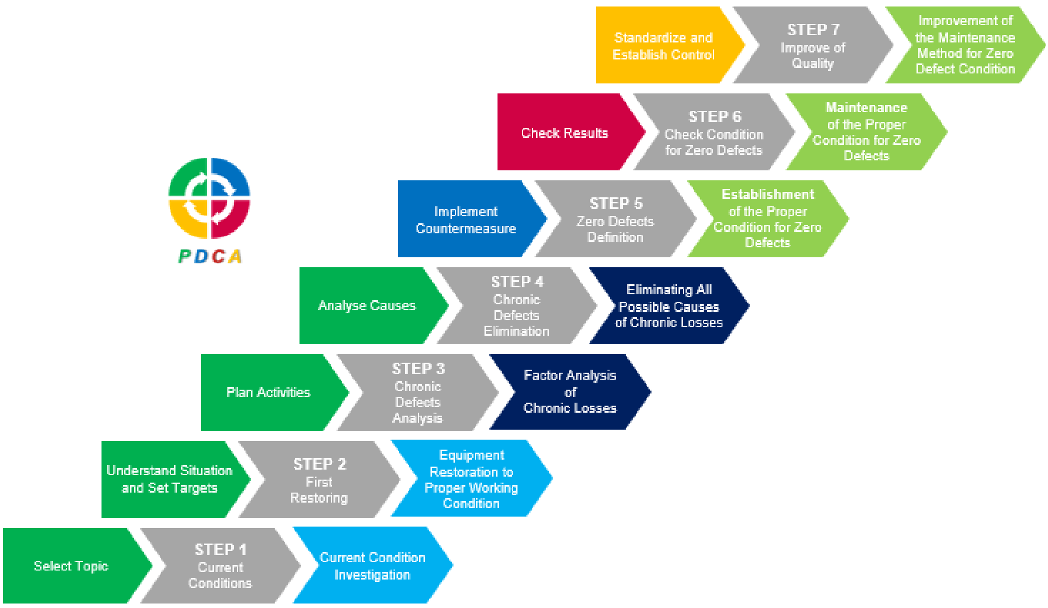



**Fig. 27-** Problem Solving Steps using PDCA

Each step refers to a specific activity that the functional problem-solving team must perform.

*Step 1:* topic is selected, and phenomena described through 5W1H method and containment actions are taken. They are useful to protect the final customer and reduce the negative effects of the phenomena.

*Step 2:* target and objective are set. To do this, is important to describe how the system works in normal conditions and list which are the key components, key phases of the process, functional parameters and main factors influencing the system. Objectives are set using "SMART" approach (Specific Measurable Achievable Relevant Time bound).

*Step 3:* problem solving activities are planned to reach defined targets. In this phase, main losses deriving from the problem are established and chronic defects are analyzed.

*Step 4:* root cause is investigated and possibly validated reproducing the phenomena on a statistical significant sample parts. To investigate the root cause are used the 7 quality tools and 5Whys method.

*Step 5:* countermeasures needs to be applied to avoid re-occurrence of the issue and/or to stop the production process phase when the problem occurs.

*Step 6:* results are checked, not only in terms of solution effectiveness, but also in terms of costs. The B/C calculation should give an evidence of the benefits obtained implementing the countermeasure. Results shall be evaluated on a consistent time gap, at least three months from the date of actions implementation.

*Step 7:* the last step consists in describe how the implemented actions and countermeasures are horizontally extended to prevent the re-occurrence of the same issue on similar components. To have an evaluation of the robustness of the implemented corrective action, 5 questions for zero defects tool can be used. In this last phase, lesson learned report is filled up.

However, it is important to give an idea of the logical and practical flow of activities to be carried out during the problem-solving phase. The following graph shows a flowchart that explains the steps and interactions between the 4 different phases of the PDCA.

The step of transition between the plan phase and the do phase require a root cause validation process. Once the phenomenon that leads to the problem has been validated, and therefore intuited, it is possible to proceed with containment countermeasures.

It is also important to perform a validation process between the Check phase and the Act phase. In fact, to move from one phase to the other, it is important to check that the horizontal extension of the countermeasures adopted, i.e. the application of the introduced innovations also to other company division, effectively give the expected results of defect reduction.

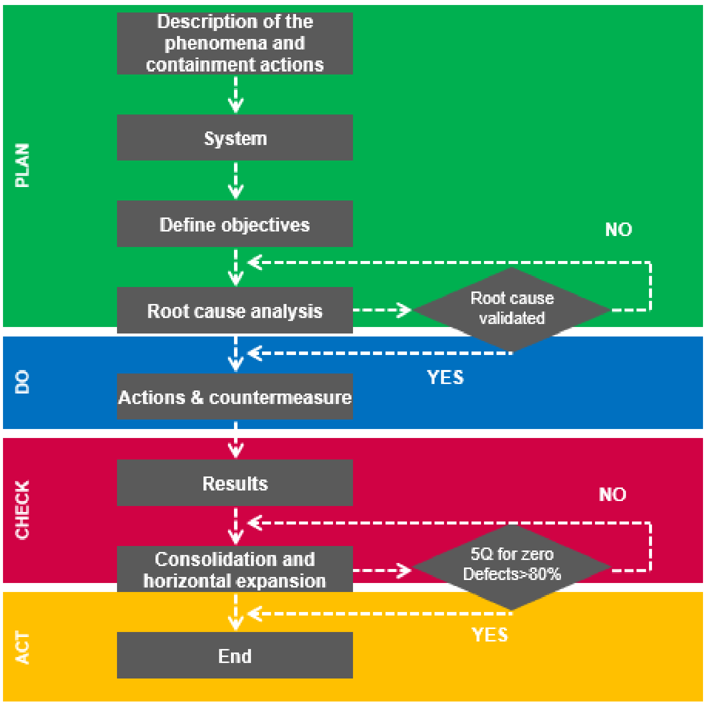



**Fig. 28-** Problem Solving process flow chart

## 4.7 Problem Solving Tools

As explained in the previous paragraph, problem solving must be structured in precise and schematic steps, which define its logical flow. At each step, corresponds a tool to be applied. Most of the tools to be implemented belong to the TQM family, explained in chapter 2.

During the first phase of describing the **phenomenon**, the most useful tool to use is 5W + 1H. In fact, this tool allows to have a broad vision of the problem and to avoid neglecting important factors that can influence the phenomenon.

After the Phenomenon description phase, is important to investigate the defect, and the best tool to apply is the Ishikawa. The Ishikawa allows in fact to investigate the **root causes**, analyzing every possible factor regarding the 5 main sources of defects: Machine, Man, Method, Material and Design. After the Root Cause is investigated, is important to validate it. This is possible using statistical tools (scatter diagrams, pareto charts, histograms) able to reproduce the phenomena on a statistical significant sample of parts.

Once the area of the defect has been identified, it is important to understand why that specific failure happened, and it is possible to do it schematically through the 5Whys tool.

After that the cause of the failure has been identified, it is imperative to attack it through corrective or containment action. The suitable corrective action is chosen through the "Benefit over Costs" method (B/C). This tool analyzes all the potential solutions to be implemented, evaluating for each of that the payback in one year, the benefits and the costs, finally making the ratio between them. Obviously, the action to be implemented will be the one with the highest B/C. This is because obviously the goodness of corrective action is greater when the benefits are as high as possible, and the costs are very small.


**Fig. 29-** Problem Solving tools used in each phase

The problem-solving activities listed above are usually grouped into a schematic report, which gives a methodological approach to the tasks to be performed. This report usually used is called 8D Report.

This report illustrates 8 important troubleshooting steps.

8D Report:

**D1.** *Team Construction*

Establish a team of people with product/process knowledge. It is important to choose people with cross-functional characteristics both at competence and decision-making level.

**D2.** *Define and Describe the problem*

Specify the problem by identifying in quantifiable terms the who, what, where, when, why, how (5W1H) for the problem. Once the team is operative, it is important to share all the information within the team and set a goal based on the analysis performed.

**D3.** *Develop a temporary containment action*

The purpose of the containment action is to limit the impact of the problem on the customer's point of view. A containment action may also concern a phase of the production process, such as a 100%-piece end-of-line check, or in any case applying actions not commonly foreseen in the cycle. The containment action must be activated promptly.

**D4.** *Individuate and Verify the Root Cause*

Identify all applicable causes that could explain why the problem has occurred (5Whys or Ishikawa). Usually the root cause is addressable to one of the fundamental variables of a process (5M: Method, Material, Manpower, Machine). Is also important to understand why the problem has not been noticed at the time it occurred. Once individuated, the cause needs to be validated.

**D5.** *Identify and chose permanent corrective action*

Through pre-production programs quantitatively confirm that the selected correction will resolve the problem for the customer.

**D6**. *Implement and Validate corrective action*

Define and implement the best corrective action, using B/C tool to choose the best one to apply.

**D7**. *Take Preventive Measures*

Modify the management systems, operation systems practices, and procedures to prevent reoccurrence of this and all similar problems

**D8.** *Congratulate the team*

Recognize the collective efforts of the team. This team needs to be formally thanked by the organization.

After that the 8D steps are performed, is very important to implement an horizontal expansion of the action and countermeasures to prevent the re-occurrence of the same issue on similar components or parts. This phase is of paramount importance to reach a World Class level, since the corrective action needs to ensure the zero defects condition. This Zero-Defect condition can be reached through the 5Q for Zero Defects. The 5Q are simply a dedicated set of 5 questions to be answered for each M.

It is a WCM tool based on the results obtained by mean of Ishikawa tool, useful to evaluate how much is robust the corrective action in supporting the conditions for zero defects.

For instance, regarding the Material, the 5 Questions could be:

1. Are the material characteristics clear?
2. Are the material characteristics easy to check?
3. Are the non-conforming materials easily stored out?
4. Are the problems easy to repair?
5. Are the suppliers capable to deliver only good parts?

This tool finds its goodness when at least 80% of the questions reach a positive level. In this case, is possible to confirm the Zero-Defect condition of the corrective action.

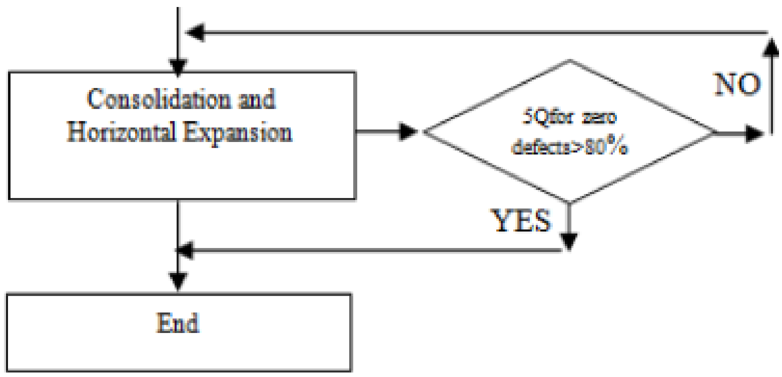



**Fig. 30-** 5Q for zero defects

# CHAPTER 5

## CASE OF STUDY

## LAMBDA SENSOR

## 5.1 Introduction

The following chapter deals with the work done in cooperation with CNH Industrial, specifically in FPT Industrial. The chapter is divided into the following sections.

In a first moment, the importance of the After-Treatment Systems (ATS) in the commercial vehicle will be discussed from a technical point of view.

The role of the Product Quality Support division will then be introduced, explaining its function and its importance during the Problem-Solving phase.

Subsequently, the practical case of Problem Solving will be discussed. A lambda sensor failure will be studied. Starting from the cost deployment and the analysis of KPI, the phenomenon and the defect will be studied, arriving till the root cause identification. Countermeasures will be proposed for the resolution of the problem, and they will be horizontally extended, arriving at the end to a lesson learned useful for the growth of the company and for the achievement of a World Class Quality Status.

### *5.1.1 CNH Industrial*

CNH Industrial was born in September 2013 after the fusion of two important brands, Fiat Industrial S.p.A. and CNH Global. It is one of the world's largest capital goods companies, producing mainly agricultural equipment, construction equipment, trucks, commercial vehicles, industrial and marine powertrains.

CNH industrial is composed by several brands, such as Iveco, FPT Industrial, New Holland and Case Construction, presenting 64 manufacturing plants all over the world.

CNH plants implement WCM, adopting a continuous improvement philosophy, plotted through the elimination of waste, and the increase of the quality of the products. There are 25 plants awarded with bronze WCM medal, 15 with silver medal and the Madrid commercial vehicle Plant with Gold Medal [25].

FPT industrial is the brand that produces engines for industrial, agricultural, marine or commercial vehicles. Sustainability is one of the key points of this brand, not only from the point of view of the factories, but also for what concerns the emissions of the engines themselves.

To maintain the leadership in the market, sold vehicles must be efficient, reliable and environmental friendly.

For this reason, the after-treatment system of the vehicles plays a key role in the quality and technological innovation of the products sold by CNH Industrial.

*5.1.2 After Treatment System (ATS)*

After treatment system is a set of components aimed to drastically reduce vehicles pollutant emission.

The major pollutants produced by vehicles are:

- CO
- NOx
- HC
- PM

The quantities of each of these pollutants vary according to whether the considered engine is diesel or gasoline engine.

The engine considered in the case study is a diesel one.

European Emission Standards (EURO) define the acceptable limits for exhaust emissions of new vehicles in the EU member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.

The stages are typically referred to as Euro 1, Euro 2, Euro 3, Euro 4, Euro 5 and Euro 6 for light Duty Vehicle Standards. The corresponding series of standards for Heavy Duty Vehicles use Roman, rather than Arabic numerals (Euro I, Euro II, etc.) [26].

The most recent legislation, the Euro 6, requires for diesel engine, the use of the following components in the ATS system:

- EGR – Exhaust Gas Recirculation
- DOC – Diesel Oxidation Catalyst
- DPF – Diesel Particulate Filter
- SCR – Selective Catalytic Reduction

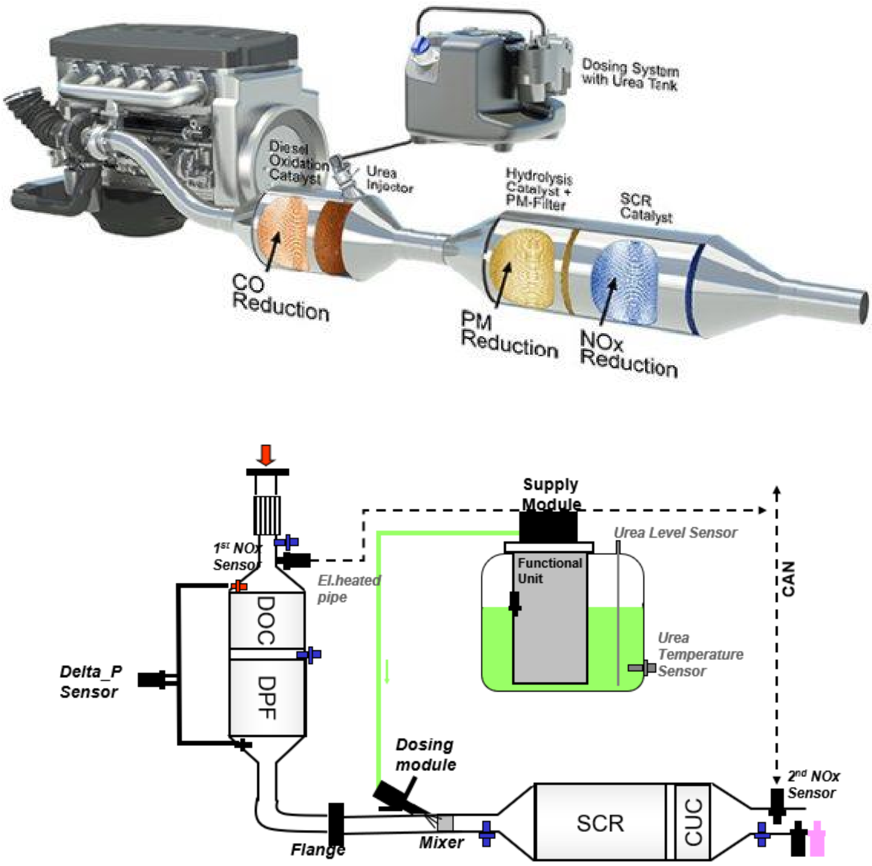



**Fig. 31**- Exhaust Gas ATS layout

It is important to underline that each component performs a specific function. The DOC has the task of reducing carbon monoxide emissions, oxidizing it and making it carbon dioxide. The DPF traps the particulates, reducing their emissions. The SCR has instead the task of reducing NOx emissions through the injection of AdBlue in the exhaust system.

The engine under study belongs to the EURO 5 Emission category. In the following, some image about the layout of the ATS considered.

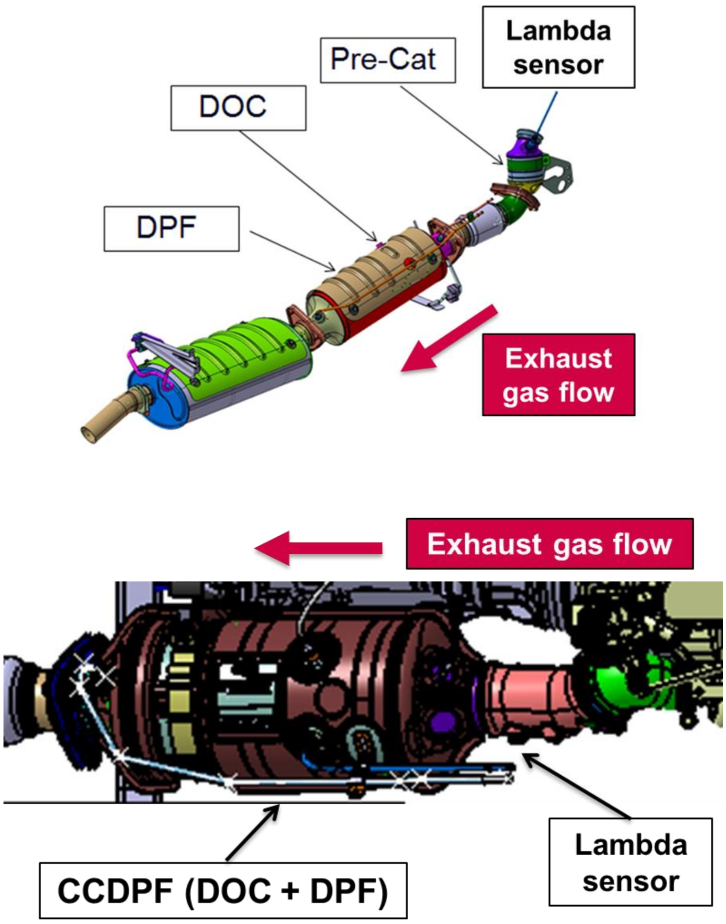



**Fig. 32-** ATS Layout – Oxygen sensor detail

Is it possible to notice that the SCR in this layout is missing.

In addition to the components discussed above, it is important to underline the presence of several sensor, having the purpose of monitoring the engine and ATS working condition, sending signals to the ECU that manages the engine operational mode. These sensors are:

- Lambda Sensor
- NOx Sensor
- NH3 Sensor (Euro 6)
- PM Sensor (Euro 6)

Lambda Sensors, or Oxygen Sensors, plays an important role in the ATS. They are used to measure the exhaust-gas concentration of oxygen for internal combustion engines in order to calculate and, if required, dynamically adjust the air/fuel ratio so that catalytic converters can work optimally, and also determine whether a catalytic converter is performing properly or not.

They basically work giving an output current signal in function of the quantity of oxygen present inside the exhaust gases, comparing it with the oxygen concentration in the outside air.

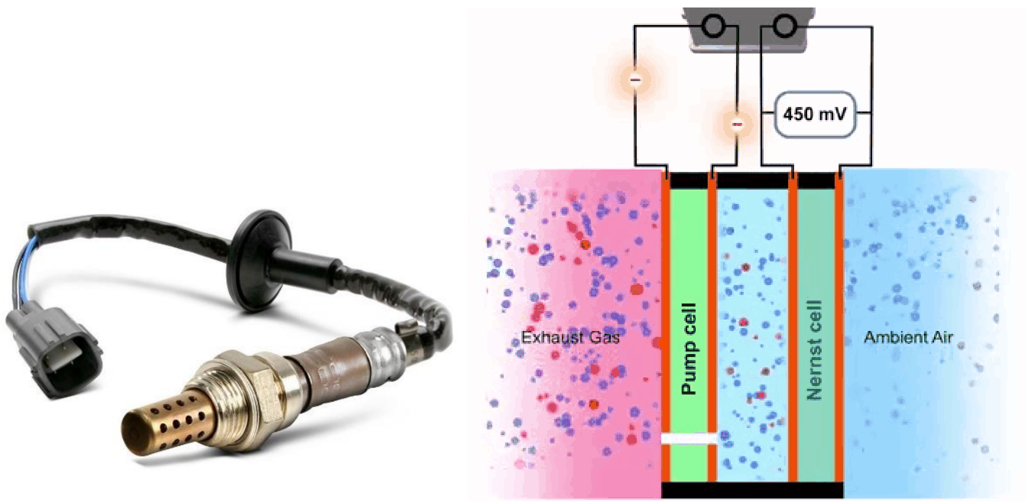



**Fig. 33-** Oxygen Sensor case (left) and Sensing Element working principle (right)

Nowadays, most used Lambda Sensor are called UEGO (Universal air-fuel heated Exhaust Gas Oxygen sensor), used to make a precise measurement of A/F ratio in an extensive range. This type of lambda oxygen sensor is therefore also suitable for lambda control with lean-burn concepts on gasoline engines, as well as for diesel engines [27].

The UEGO sensing element (also wide band sensor) has 3 components: the pump cell (Zirconia layer) the Nernst cell and the monitoring chamber. The target is to maintain the voltage of the Nernst cell at 450 mV. This can be achieved by varying the pump cell current flow. The ECU monitors its current adjusting the A/F ratio accordingly.

The exhaust gases enter inside the monitoring chamber through the diffusion gap. The Nernst cell will thus produce a certain voltage depending on the A/F ratio. The monitoring chamber should always be kept at A/F ratio of 14.7:1 that corresponds to a Nernst cell voltage of 450 mV. This is achieved by varying the pump cell current that has a direct relationship to the A/F ratio. If A/F ratio is the stochiometric one, there is no current flowing into pump cell. If there is a lean mixture, the oxygen is in excess and thus the Nernst cell voltage will drop. To compensate for this, the pump cell will have a positive current flow which will reduce the content of oxygen in the monitoring chamber. The opposite occurs dealing with reach mixture.

The following graph, shows the characteristics of this kind of sensor. It is noticeable that low A/F ratio corresponds to low voltage output of the sensor.

The change of slope indicates the passage between rich and lean mixture.

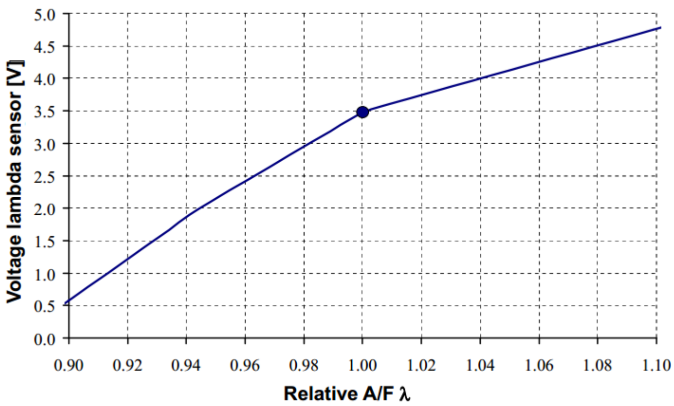



**Fig. 34** - Output voltage trend respect to A/F ratio

### *5.1.3 Product Quality Support*

The study developed, was carried out within the Product Quality Support division that deals with the ATS System.

The goal of this division is to study and solve the major quality issue founded during the development, launch, and after-sales phases of the product, aiming to achieve a zero-defect status, thanks to the extension of the lesson learned.

The term "Support" derives from the horizontality of this business function. Indeed, the purpose of this division is to interact, integrate and support engineering, application, production and development, by setting up a schematic working methodology, in order to prevent the reoccurrence of defects. In fact, a failure can derive from each of these business functions. It can come from an incorrect design of the product, from a wrong production process or from an application error. Therefore, the Product Quality Support, must understand where the failure came from, finding the root cause and try to solve it.

The qualitative process usually starts from the analysis of the KPI and the defects found in the field.

The quantity and type of failures gives an indication about the defectiveness of the components, giving guidelines about the most important components to be improved.

Once the root cause is identified, is important to support the business function from which the defect derive, integrating knowledge from the other divisions.

After that, the lesson learned must be extended. New products and new launch must have the new design, with the aim of avoiding a reoccurrence of the same defect.

At this stage, it is important to proceed in a proactive way. Possible similar defects should be not solved with reactive solutions.

Lessons learned will be useful to find and understand other potential source of failure, developing new, more robust and efficient designs able to prevent the occurrence of any defect, even if this has never occurred.

## 5.2 Data Analysis

Data Analysis is the first step of the problem-solving process.

In this section, the data analysis phase will be carried out. The meanings of the main performance indicators will be discussed, and then the practical case of data collection and analysis will be developed.

(Note that all sensitive data contained in charts have been obscured. The graphs shown below, are examples, and have the purpose to explain the essential concepts to ensure a correct logical flow).

### *5.2.1 KPI: Merf and Corf*

Every company needs an indicator to measure effectiveness and performance. Generally speaking, the performance of a firm is measured according to the turnover at the end of each year.

However, using net income as an indicator, may not be realistic in order to understand the real performance of each company division. For this purpose, specific indicators related to each activity are used.

A Key Performance Indicator (KPI) is a type of performance measurement that evaluates the success of an organization or of a particular activity. Observing the KPI trend, it is possible to understand how close or far the company is respect to the target.

In Product Quality Support, the most used KPI are MERF and CORF. These indicators refer to claims registered during warranty period.

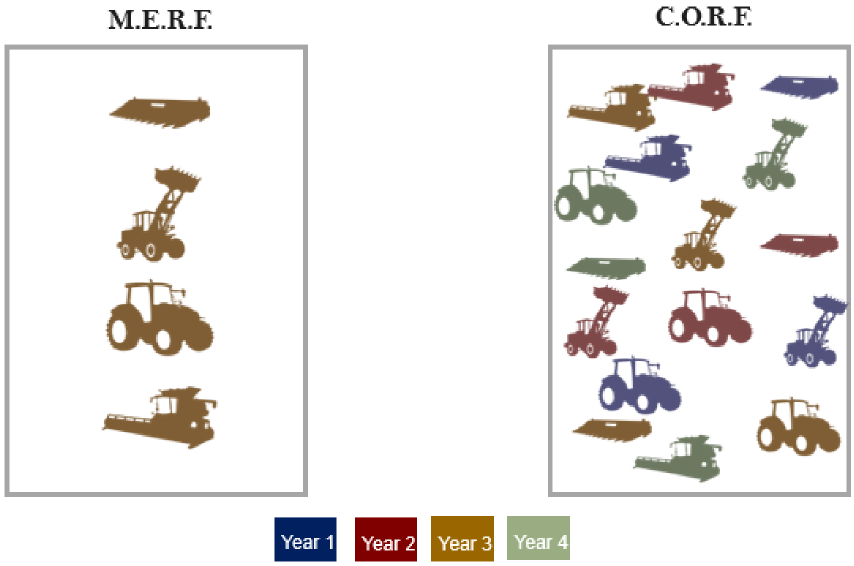



**Fig. 35-** MERF and CORF representation

MERF (Manufacturing & Engineering Repair Frequency) represents the warranty claims for a specific build period.

Instead CORF (Customer Observed Repair Frequency) represents the last 12 months of claims, no matter the build period.

As is shown in Fig. 35, MERFs are related to a specific production period. If for instance year 2 is considered, the MERF will give an indication of all the products with a failure that were produced during the year 2.

Looking at the right side of the image, is possible to understand that CORF are instead useful to evaluate the failures occurred during a certain period, for instance 6 month, or 1 year, without considering a specific production date.

However, MERF and CORF are only forms of data representation. They need some Key Metrics i.e. some specific indicators that describe the performance of a phenomenon in a measurable way, in this case failures and costs.

Failures are used as a way of measuring the customer experience. Usually they are evaluated throughout the warranty period. The failure indicator is called F100, it is simply a failure rate, and is evaluated considering the percentage of failure over a specific sample.

For example:

$$6 \text{ failures on a park of } 83 \text{ products: } \frac{6}{83} \times 100 = 7{,}22$$

Thus, in this case the F100 is equal to 7,22.

Costs are instead used as indicators to take into account the economic performance of the company. The cost indicator is called ACPU, that means Average Cost Per Unit. They represent the average warranty spend per unit across a given park.

For example:

$$\$277{,}560 \text{ spend}/401 \text{ units} = \$692 \text{ ACPU}$$

Is it possible to plot MERF and CORF in a control chart, in order to have a clear idea of the trend of these indicators.

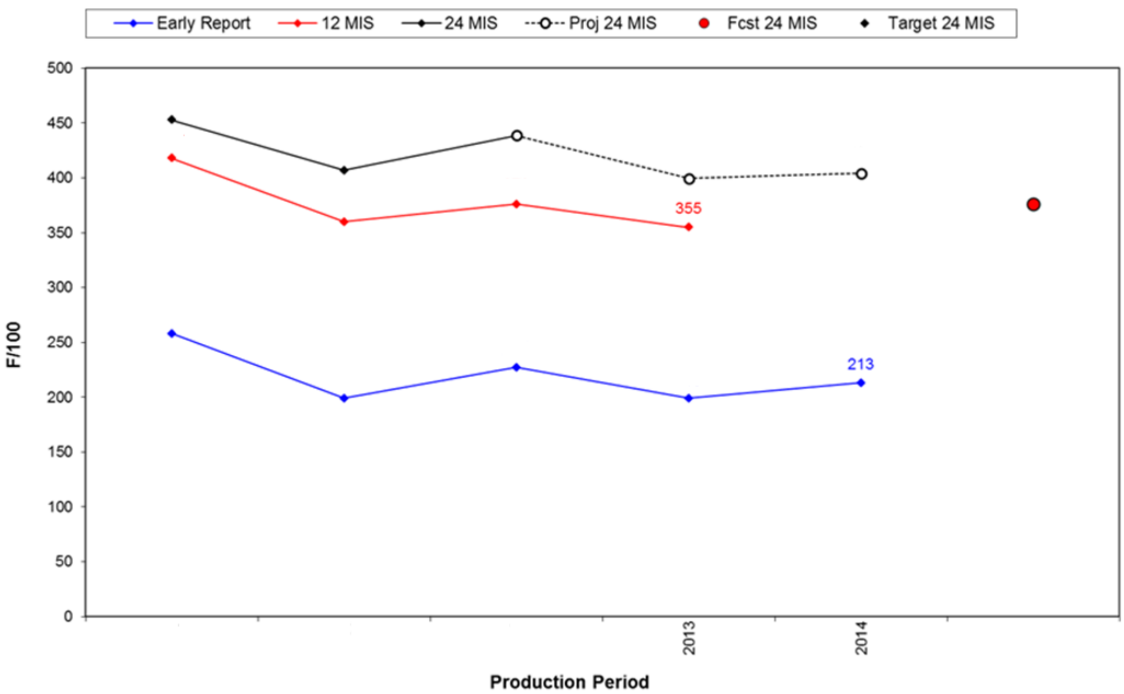



**Fig. 36-** MERF related to F100 from 2010 to 2015

This chart shows an example of F100 MERF trend. The blue line shows the failure rate for the last six months. It is clear that in the last six months, considering all the vehicles produced in 2014, 213 had a failure.

The red line instead, say that in the last twelve months, considering all the produced vehicles in 2013, 355 had a failure.

The same reasoning can be done considering ACPUs instead of F100.

The following control chart shows the CORFs trend. The black line is referred to F100.

It is noticeable that, for instance, considering September 2015, there was a total of 195 failed parts in the last 12 months, independently from the built period.

Instead, if November 2014 is considered, there was a total of 181 failed parts in last 12 months, it means that from December 2013 to November 2014, a total of 181 parts had failed.

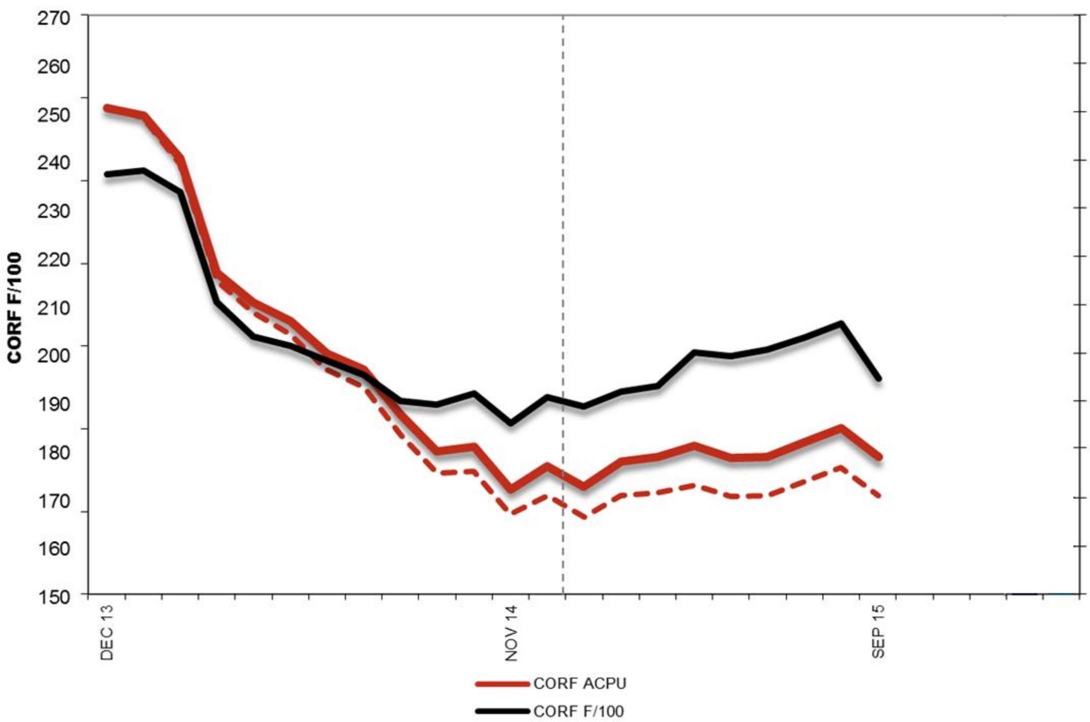



**Fig. 37-** F100 and ACPU CORF trend

### *5.2.2 Practical Case Data Analysis – Cost Deployment*

(Notice that, some data in the charts below shown have been hidden to avoid the diffusion of sensitive data for the company. Graphs are for example purposes)

The work done in CNH started from a preliminary phase of Cost Deployment. The product taken into account is the ATS of a Diesel engine of a commercial vehicle.

The failure trends and the warranty costs were analyzed in order to understand the major cost sources, trying to implement actions aimed to attack them and thus reduce wastes of money.

This work began with the MERF's trend analysis of the ATS system of a diesel vehicle, considering a stated reference period.

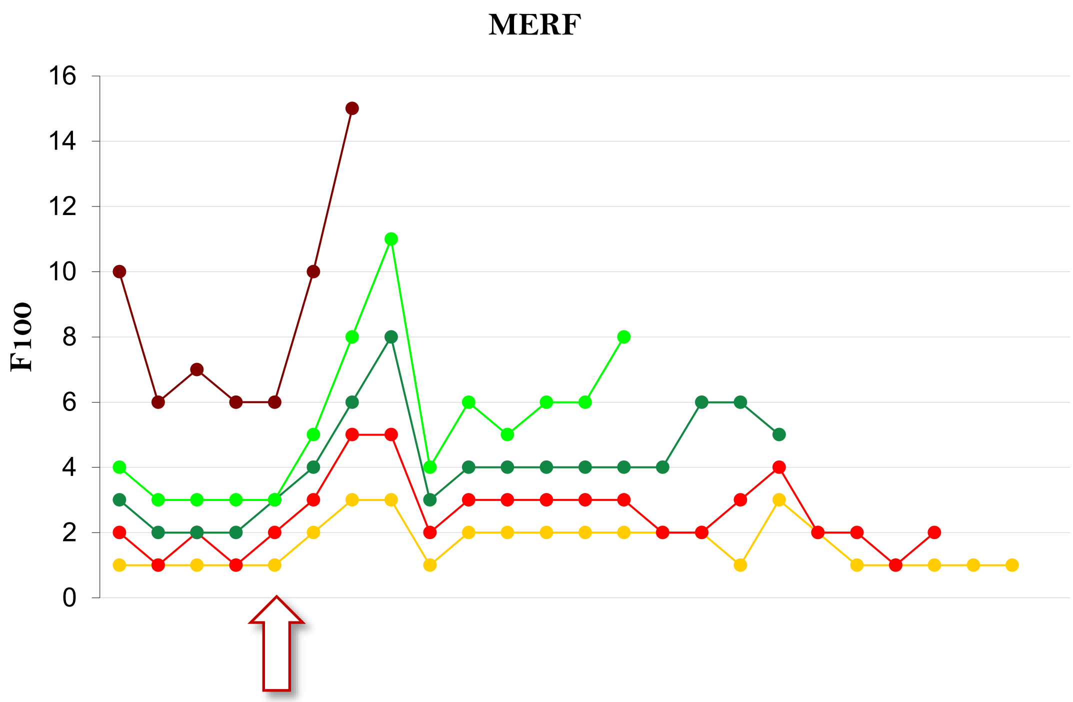



**Fig. 38-** F100 MERF trend of ATS components

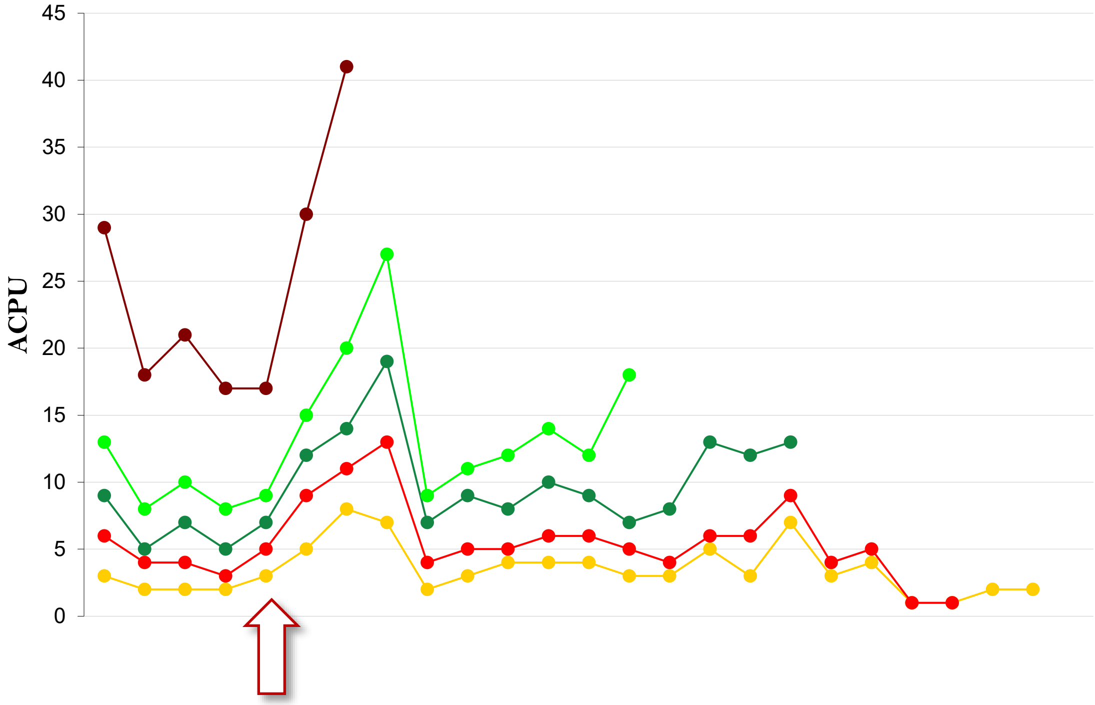



**Fig. 39-** ACPU MERF trend of ATS components

The data related to the last 12 months consolidated (orange trend) will be taken into consideration, as they are more reliable since they embrace a larger sample.

It is noticeable both from the F100 and ACPU graph (Fig. 38; Fig 39) that, from the data indicated by the arrow, the trend start rise.

This, may be due both to problems of different nature or to the occurrence of a single failure, which leads to the increase of costs. Since the line has a positive slope, it is of paramount importance to intervene, avoiding that this trend continues to increase over time.

At this stage, the nature of the problem to be attacked must be understood, analyzing the most critical components from the cost and failure rate point of view.

In the following, the Pareto diagram of the most critical components is shown.

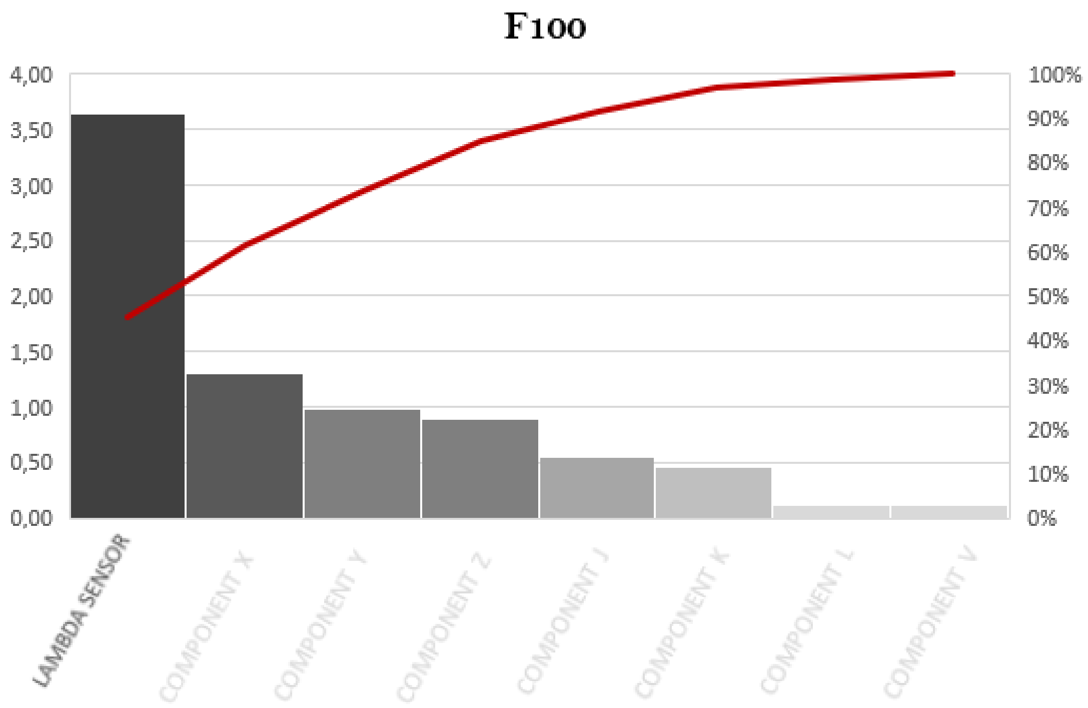



**Fig. 40-** Most critical failure rate of ATS components

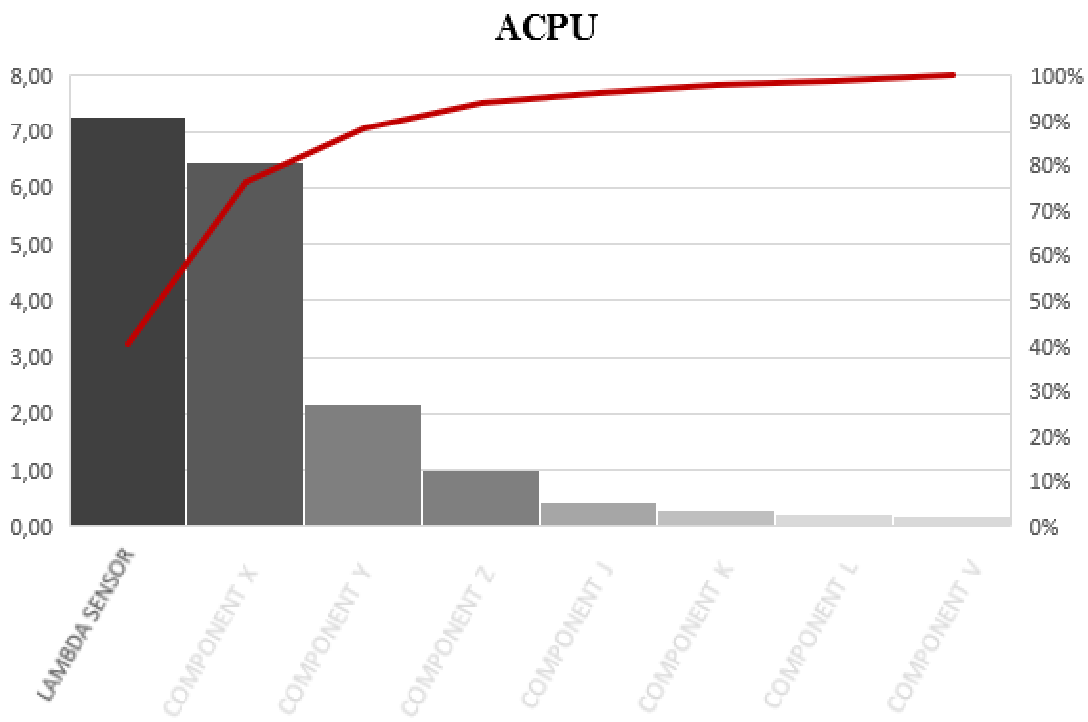



**Fig. 41-** Most critical ACPU of ATS components

From the Pareto diagram in fig. 40 is possible to notice that the component with the highest failure rate is the Lambda Sensor. Its F100 reaches about 3.6, which corresponds to 61 failures occurred in the last 12 consolidated months. This gives an indication about the component that should be attacked, but it is not enough.

As a matter of fact, the component with the highest failure rate, may not be the one that creates the highest spending. Hence, the ACPU (fig. 41) related to each component must be analyzed.

One can notice that also in this case the highest cost is associated to the Lambda Sensor. However, to define objectively which component needs a fast intervention, is important to evaluate a priority index. Indeed, through the two Pareto is possible to evaluate frequency and cost impact, but also the severity for the customer should be evaluated. A component with high frequency and cost, can create low inconvenience for the customer respect to another that can, for instance, stop definitely the vehicle.

The following table gives some guidelines for the Priority Index Definition.

| Score | Cost | Severity for Customer | Frequency |
|---|---|---|---|
| High (50) | Issue in the top positions in your MERF /CORF sorted by cost | Severe issue, compromizing customer loyalty<br>• Escalation on going / high impact on company reputation | Issue in the top positions in your MERF/ CORF sorted by frequency |
| Medium (20) | Issue in the middle positions in your MERF /CORF sorted by cost | Significant issue ,it will result in a warranty claim<br>• Emerging issue | Issue in the middle positions in your MERF/ CORF sorted by frequency |
| Low (6) | Issue in the lower positions in your MERF/ CORF sorted by cost | Issue that could be detected, by some customers, other no<br>• Alert from customer | Issue in the lower positions in your MERF/ CORF sorted by frequency |
| Minimal (3) | Cost is minimal | Normally, customer would not see it.<br>• no alert from customer | Frequency is minimal |

**Tab. VI** – Priority Index Table

| | |
|---|---|
| High | $20 < PI \leq 50$ |
| Medium | $6 < PI \leq 20$ |
| Low | $3 < PI \leq 6$ |

**Tab. VII** – Priority Index score

$$PI = 0{,}25 \cdot Cost\ score + 0{,}5 \cdot Severity\ score + 0{,}25 \cdot Frequency\ score$$

The severity for customer is high. A problem on Lambda Sensor can create legislative issues, since pollutant emissions are government regulations. Furthermore, if an issue on lambda probe occur, the diagnosis on vehicle can set a derating, implying problems for the customer.

Accordingly, one can say that the lambda sensor is the most important component to attack.

## 5.3 Phenomenon Description

Once the most critical component for cost, failure, and customer impact is found, the first step is to understand the problematic situation experienced by the final customer.

This phase involves the claim collection and the analysis of error codes stored in the ECU.

Once data are collected, the phenomenon will be schematized and described using the 5W1H methodology.

Error codes, called DTC codes, are information stored in the ECU whenever a diagnosis is set. DTC indicates a malfunctioning of some component, and these data are available to the Product Quality Support team whenever the vehicle is connected to the service tool.

### *5.3.1 Phenomenon description – 5W1H*

After the claim analysis, two common DTC were noticed: 13-121 and 13-264. The first indicates a low oxygen measurement, the second a slow lambda sensor dynamic.

Customers experienced an engine warning lamp intermittent on the cluster.

| | | |
|---|---|---|
| **What** | **What** did happen? | Mil On – Lamp on cluster (DTC 13-121 and 13-264) |
| **Where** | **Where** it was noticed? | On ATS – Upstream Lambda Sensor |
| **When** | **When** the problem occour? Did it occour sistematically? | After 3 driving cycles at low mileage (700-4102 km) during cut-off |
| **Who** | **Who** was responsable of the problem? | Issue not related to final customer |
| **Which** | On **Which** applications? | On 17 commercial vehicles with diesel engine configuration |
| **How** | **How** the problem occrred? | Lambda sensor read low oxygen and has a slow dynamic |

**Tab. VIII** – 5W and 1H table for oxygen sensor issue

Using the 5W1H table, is possible to have a wide configuration of the phenomenon.

Nevertheless, further studies must be carried out to find the real cause of the problem. The reason for the diagnosis set could also be a malfunctioning of the engine, which in cut-off mode continues to burn fuel.

Before starting the root cause study, it is important to analyze the technical specifications of the Lambda Sensor.

As it is noticeable from the following image, the considered lambda sensor is the upstream one, the first encountered by the exhaust gases exiting from the exhaust manifold. It is able to measure the residual oxygen content in exhaust gases with a continuous wide range signal from A/F=0.65 to air value. During Cut-Off condition, the fuel is not injected, no combustion occur, thus the Lambda Probe should read an oxygen percentage of 21%.

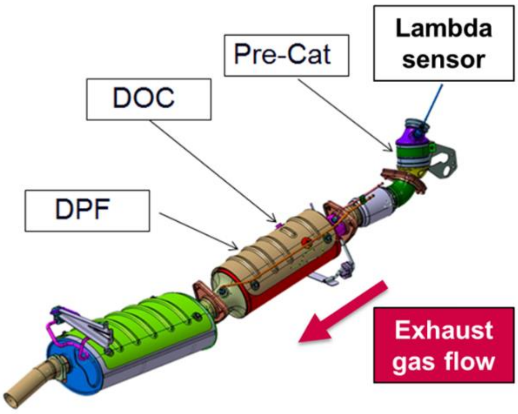



**Fig. 42-** Upstream Oxygen sensor

The sensing element at the center-front of the sensor consists of a zirconium dioxide sensing element enclosed within a steel shell. The sensing element is further connected to platinum electrodes and wire leads down the line.

In the following, a longitudinal cross section of the considered Lambda Probe.

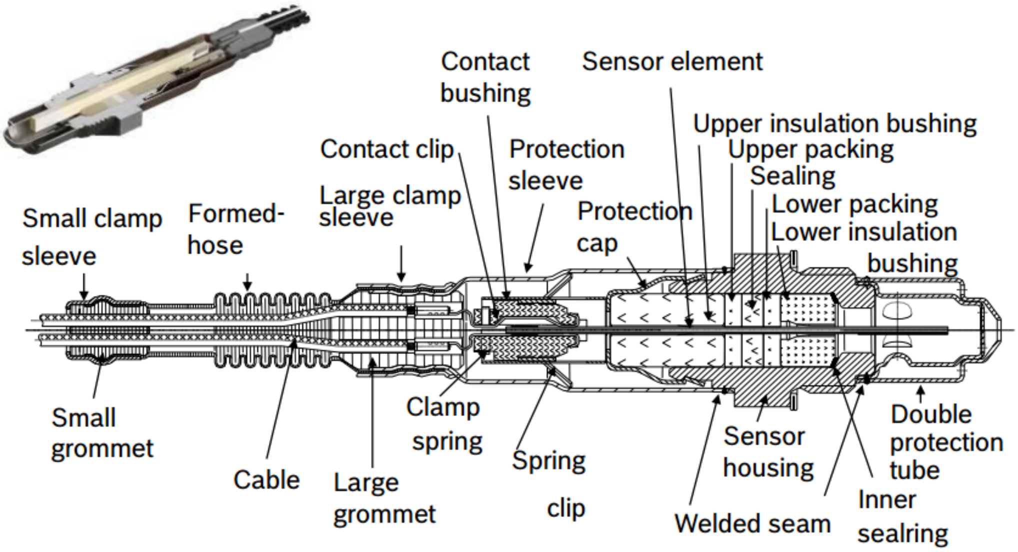



**Fig. 43-** Oxygen sensor section. Major components are evidenced.

The measurement of the oxygen content is performed by the electrode present inside the sensor element.

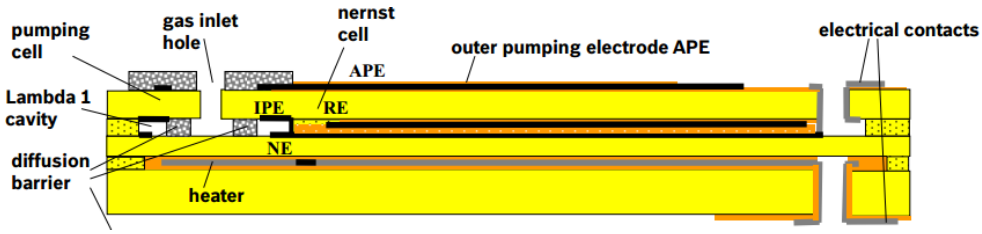



**Fig. 44** – Sensing element detail

For the measurement of the oxygen content the electrode of the lambda sensor has to fulfill the following task:

- Absorption and Dissociation of $O_2$ on the platinum grains;
- Diffusion of $O_2^{--}$ ions on the surface of the electrode;
- Entrance of $O_2^{--}$ ions into the ceramic at the three-phase boundary (Zirconia, Platinum, Gas).

This sensing element present an electrochemical gas pump. An electronic circuit containing a feedback loop controls the gas-pump current to keep the output of the electrochemical cell constant, so that the pump current directly indicates the oxygen content of the exhaust gas. This sensor eliminates the lean–rich cycling inherent in narrow-band sensors, allowing the control unit to adjust the fuel delivery and ignition timing of the engine much more rapidly [28].

The A/F value is thus proportional to a current generated by the potential difference due to different oxygen concentration. The output voltage characteristic read by the ECU presents the following trend.

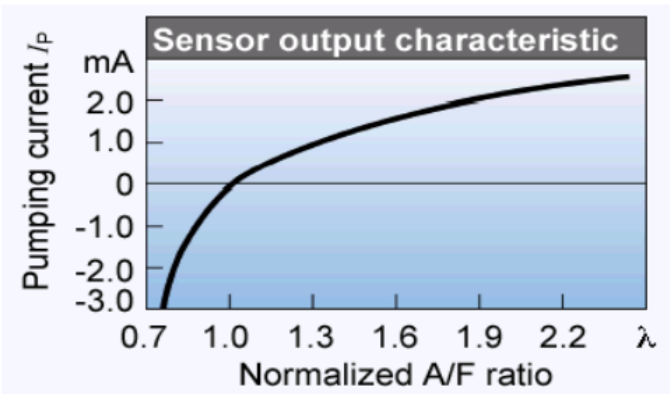



**Fig. 45**– Output pumping current characteristic

## 5.3 PLAN: Root Cause Analysis

Once the phenomenon is understood, the investigation phase of the problem can start.

In order to exclude the possibility of an engine malfunctioning, functional tests on claimed sensors have been carried out.

These tests consisted in monitoring the lambda probe voltage output in some specific driving condition. Claimed sensors were analyzed driving vehicles in cut-off mode.

The test on sensors shown a measured oxygen quantity of 14%-16% respect to an expected value of 21%. The test was repeated after having cleaned the sensor with compress air. The result was the same.

After that, the lambda sensor was replaced with a new one, in order to exclude the possibility of an ECU/Engine malfunctioning. In this case, the test gave positive results.

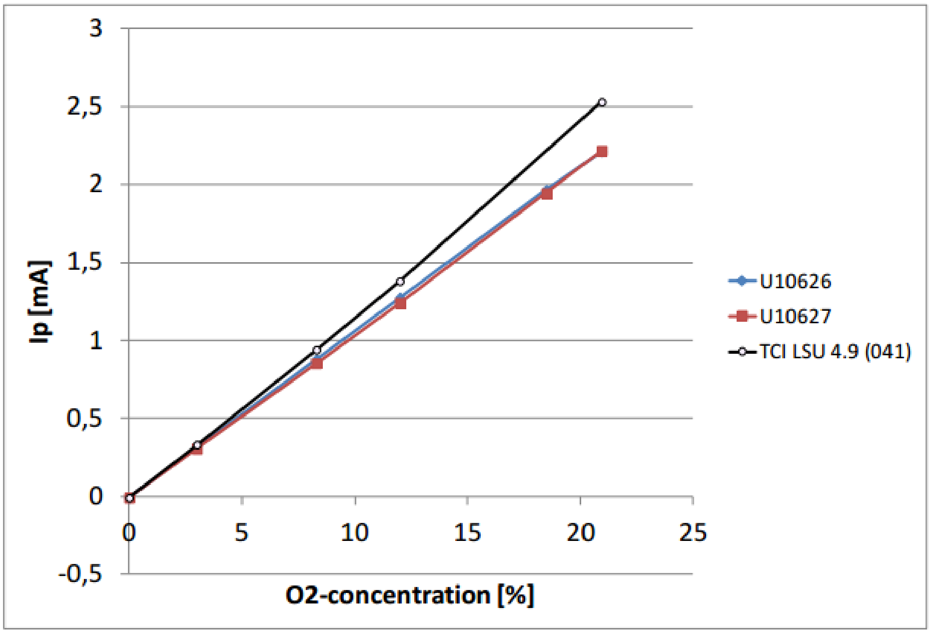



**Fig. 46** – Current signal characteristic shifting respect to normal operation

The above graph shows the current signal respect to the oxygen concentration. The characteristic of the failed sensors are the red and blue ones: they are shifted down and bent respect to the correct one. This is probably due to a poisoning of the electrodes.

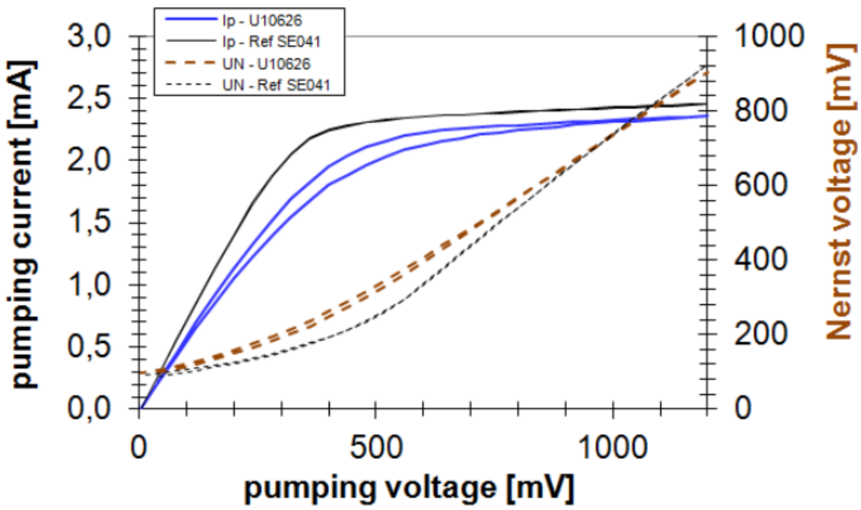



**Fig. 47** – Pumping current drifting respect to pumping voltage

Also from the above graph is possible to notice that the resistance of the pumping cell is increased, and the Nerst voltage of the failed sensor is shifted to the left (blue line). This increasing of resistance indicates a possible damage of the sensing element.

In this phase of the root cause analysis, failed items must be studied. Experience suggest that the possible cause of a shifted characteristic is the poisoning or damage of the sensing element, or a poor conductivity of the Zirconia layer.

Electrode can be poisoned by element such as Silicon, Phosphorus and their compounds.

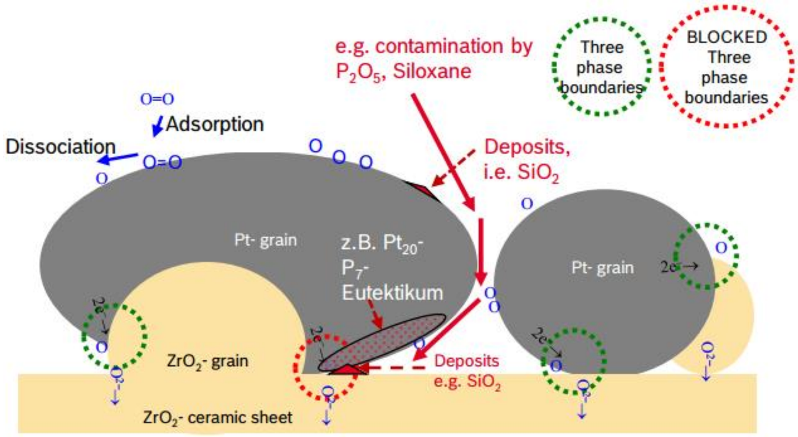



**Fig. 48** – Example of Three Phase Boundary contamination

As is shown from the previous image, in case of $SiO_2$ contamination, this compound blocks the $O^-$ access at the three-phase boundary, the surface of the electrode is affected, and the consequence is a reduction of electrode's pumping capability. Once the electrode reserve is used-up, lambda characteristic line shifts down.

Another possible cause of the shifting is the brakeage of the component. This could occur due to hydrothermal aging of the sensing element zirconia layer.

Hydrothermal ageing of sensing element can be caused by extreme extended operation at low exhaust gas temperature and high humidity.

In order to have a clear and schematic idea of all possible cause of the problem, a failure tree flow chart can be drawn.

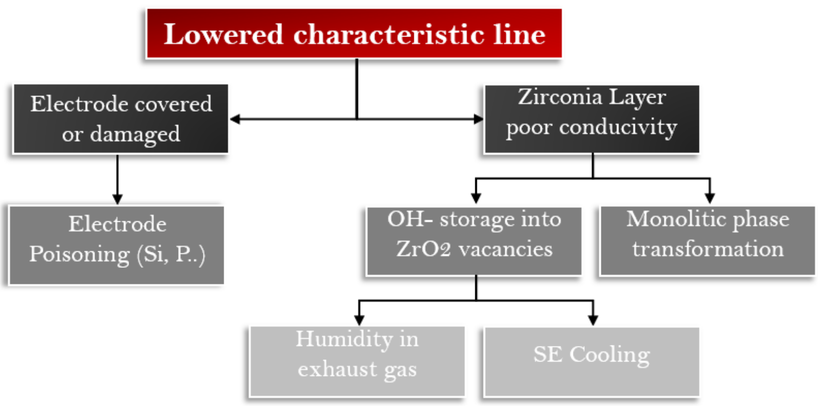



**Fig. 49** – Failure tree flow chart

A deeper analysis on the component is required in order to understand the problem. In a first moment, a visual inspection on the component was performed to check the possible presence of breakage, damage, deposits and/or corrosion. Visual checks are always the first step for root cause analysis. They do not require high investments in money and time, and very often they give an immediate idea of the cause of the problem.

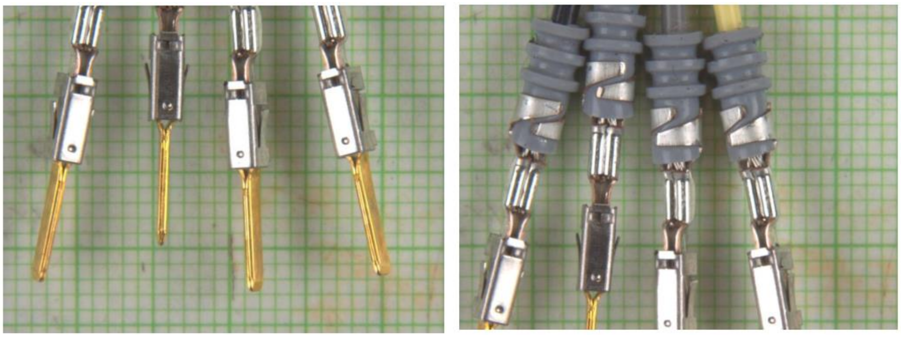


**Fig. 50** – Sensing Element

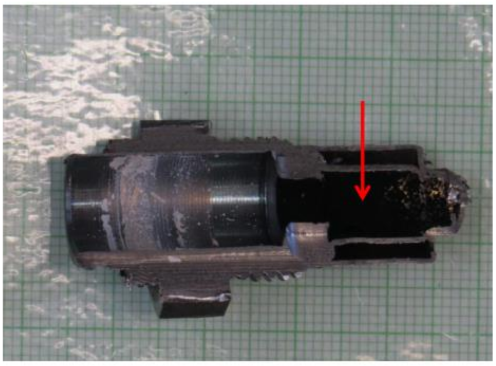


**Fig. 51** – Protection tube. Presence of soot indicated.

Visual check on sensing element (Fig. 50) showed no construction or use defect, and no trace of deposits or corrosion.

Indeed, the protection tube (Fig. 51), showed a high presence of soot in the inner face.

The second step, is to perform a chemical analysis on the sensor.

Sensing element was first analyzed on three different spots. The analysis revealed presence of Silicon, Carbon Sodium and Aluminum in small quantities.

Chemical analysis on protection tube showed high presence of Carbon, Aluminum, Zinc, Silicon, Phosphorus and Manganese. Furthermore, traces of oxidation were present.

The deposits above mentioned possibly restrain the surface diffusion and may also cover the triple phase boundary, causing thus a shift of the characteristic line.

The presence of contaminants can be justified in several ways.

Ishikawa is the most powerful tool to analyze all possible root causes and possibly exclude the least relevant one.

As explained, Ishikawa is divided into several fields:

- System
- Environment
- Management
- Material
- Process

For each area, possible problems are listed.

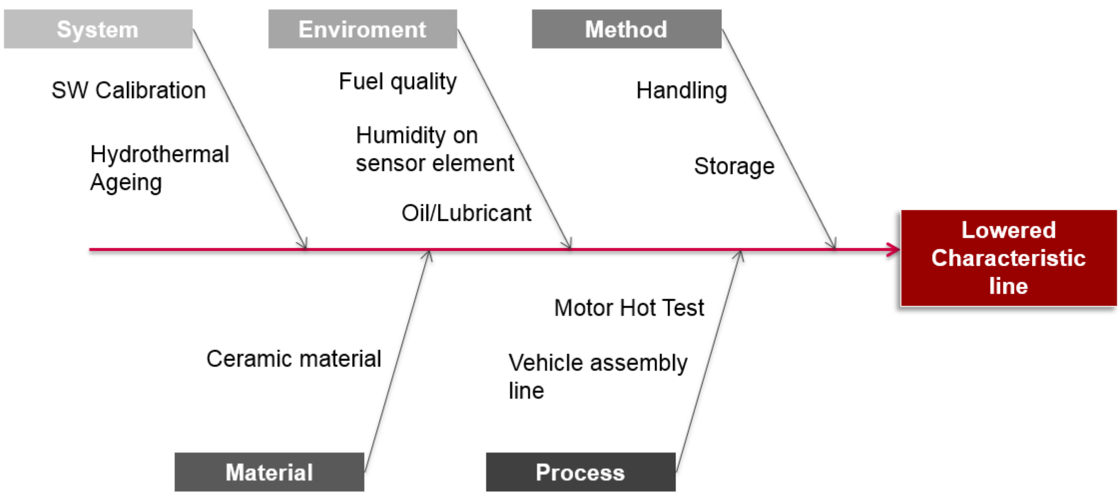



**Fig. 52** – Ishikawa for Lowered Characteristic Line

It is important to highlight that the Ishikawa in fig. 52 shows all potential root causes, which are not definitive. A targeted analysis will show which are the most plausible and which ones are to be excluded.

In the following, the potential root causes are briefly listed.

- *Oils/Lubricant:* excessive soot is due to high engine oils or lubricants ingress. These compounds, can burn in the combustion chamber leading to a high quantity of soot in the exhaust gases;
- *Fuel Quality:* wrong fuel additives lead to presence of hashes after combustion;
- *Humidity on the sensor:* humidity can lead to an incorrect current signal due to changing in resistance characteristic, or can evaporate, inducing an increase of pressure braking the sensing element;
- *Hydrothermal ageing:* extreme extended operation at low exhaust gas temperature;
- *Ceramic Material:* Zirconia Layer degraded. Transformation from tetragonal to monolithic in sensor $ZrO_2$ element structure;
- *Handling:* operators can cause the component to fall/handle incorrectly, leading to a damage or contamination;
- *Storage:* component can be stored in a humid environment, causing sensing element poisoning;
- *Motor Hot Test:* release of silicones by evaporation during initial engine operation, for example from oxidation catalyst or exhaust mats;
- *Vehicle assembly line:* wrong assembly process can cause rupture;
- *SW Calibration:* calibration and diagnosis set can be too susceptible to contaminants.

From the Ishikawa it is possible to deduce that contaminants, such as oil, soot, humidity or other elements is the main cause of the problem.

Incorrect handling and assembly are also potential root causes.

Once defined the potential root cause, it is important to divide the problem into two macro areas in order to clarify which are the major intervention field and apply eventual countermeasures.

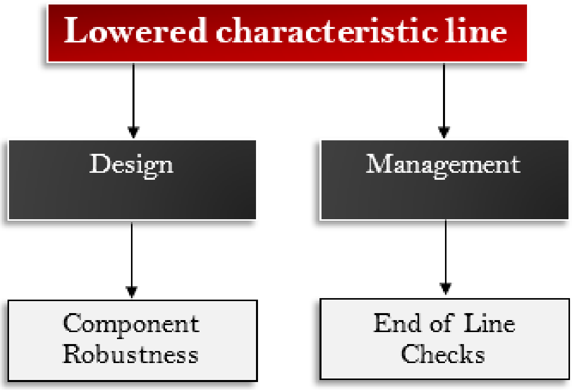



**Fig. 53** – Two macro areas for potential root cause

In order to verify the goodness of the handling phase in the production process and exclude it as potential root cause, end of line check is necessary. This verification can be considered a temporary countermeasure to avoid the production of further non-functioning items, and to verify the goodness of the production process.

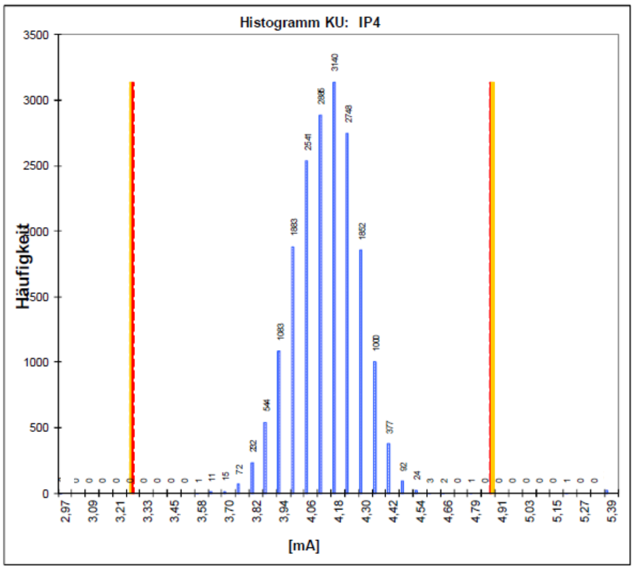



**Fig. 54** – Tested components gaussian distribution

End of line test must be performed on 100% of the production lot for a certain amount of time. This test consists in verify the pumping current electrical characteristic of the sensing element. The Fig. 54 diagram, shows the distribution of the tested components.

One can notice that the distribution is normal, and all the components are inside the acceptable limits.

This conclusion excludes the possibility of a production line problem and therefore, the study can be restricted to the product design area. Software calibration is another root cause that can be excluded since widening the limits within diagnosis sets up would compromise the reliability of data reading, and thus the ECU would manage imprecisely the engine operation modes.

The modified Ishikawa resulting from these consideration is the following.

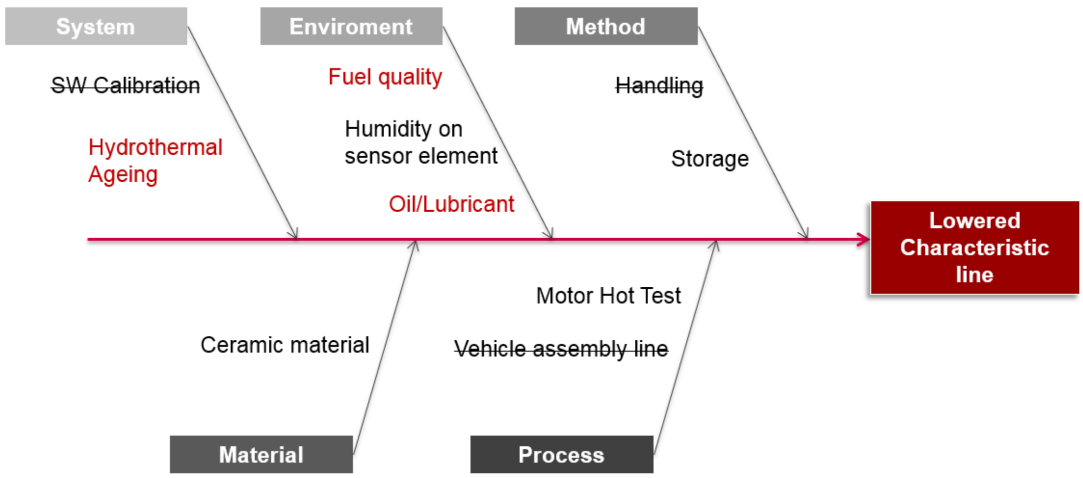



**Fig. 55** – Ishikawa. The most probable causes are highlighted

One can notice that all not excluded root causes lead to a lack in component design. The robustness lack of the component against external contaminants is the principal root cause. Improving the component robustness against contaminants and humidity, allows the electrical characteristic to remain unchanged even in hard working conditions, the oxygen reading is thus consistent, and the diagnosis should not be set. Below are listed the 5Whys that led to the detection of the root cause. Even if the Ishikawa shows the presence of problem of potential different nature, all these can be resumed in a single design issue that, if attacked, should avoid the phenomena occurrence.

| **5 Why Question Table** | |
|---|---|
| **Team Members:** | |
| **Problem Statement:** Driving in cut-off mode, MIL on light on the cluster | |
| **Recommended Solution:** Increase the number of potential interface region in the TPB of the Oxygen Sensor. | |
| **Why Question** | **Answer** |
| **1. Why** there is a lack in component robustness? | Because there is a reduction of electrode's pumping capability |
| **2. Why** there is a reduction in pumping capability? | Because $O_2$ Ions do not diffuse on the electrode surface |
| **3. Why** Ions do not diffuse on the electrode surface? | Because some contaminants block the entrance on three-phase boundary |
| **4. Why** contaminants block the entrance on three-phase boundary? | Because TPBs has low electrode reserve |
| **5. Why** TPBs has low electrode reserve? | Because there is a low number of potential interface region |

**Tab. IX** – 5Whys question table for oxygen sensor issue

The following diagram shows a reverse logical approach. It is possible to notice that by attacking the root cause, one arrives in reverse way to the resolution of the phenomenon.

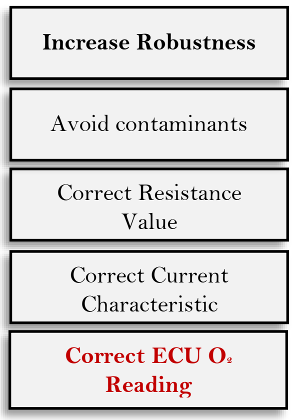



**Fig. 56** – Reverse logical approach flow chart

## 5.4 DO: Corrective Actions

After the potential root cause is understood, is important to attack the problem by implementing some corrective actions. These actions can be supplementary or can involve in a direct way the component design.

As said before, the sensing element is the part subjected to contaminant or humidity interaction. The three-phase boundary is the surface of the sensing element. It is called three-phase since it is a contact region of three different phases, in our case Platinum, Zirconia and Oxygen.

In order to correctly measure the $O_2$ content the TPB has to fulfill the following task:

- Absorption and dissociation of Oxygen on the platinum grains;
- Diffusion of $O_2^{--}$ Ions on the surface of the electrode;
- Entrance of the ions into the ceramic at the three-phase boundary.

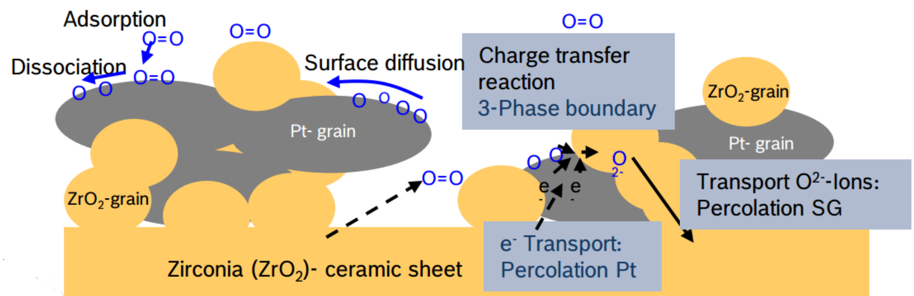



**Fig. 57** – Three Phase Boundary working principle

As previously explained, if contaminants are present in the three-phase boundary, $O^{--}$ can be blocked, not having the possibility to diffuse.

TPB requires thus an improved design in order to avoid an excessive sensibility to external agents.

The solution is to increase the number of three phase boundaries. Doing that, the increased number of potential interface region lead to an higher probability for the oxygen to enter in contact with the TPB and diffuse, even if some contaminants are present.

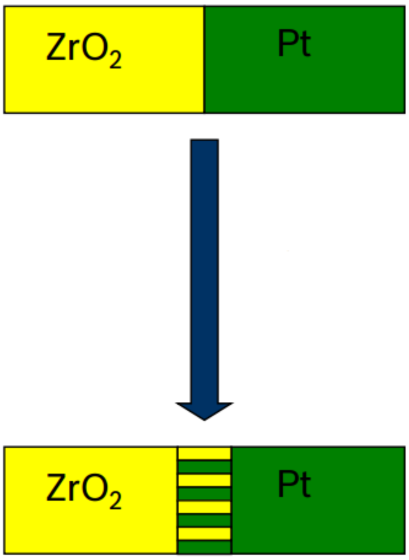



**Fig. 58** – Conditioning Process scheme

As shown in fig. 58, the second arrangement allows to have a higher number of interfaces. This configuration has more active three phase boundaries than necessary, which gives a so-called electrode reserve. To do that, a conditioning process of the electrodes is necessary. Conditioning process new parameters can be implemented in the production line, optimizing the electrode reserve.

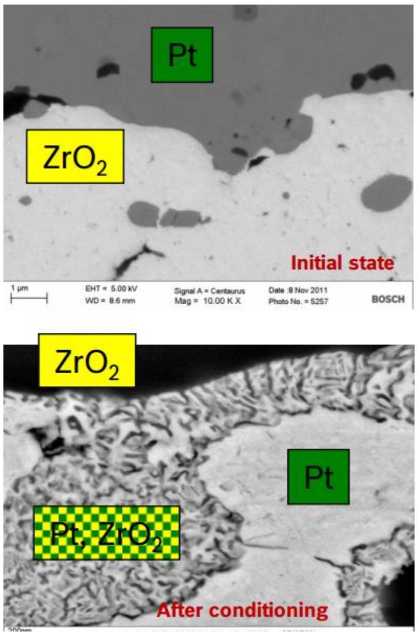



**Fig. 59** – Comparison between TPB without and with conditioning process

## 5.5 CHECK: Corrective Actions Validation

Each new component introduced requires a validation phase. Even if the component has minor changes, tests are necessary. Indeed, a new design can interact with the system in which the component is introduced in an unpredictable way. A series of tests are necessary to evaluate the goodness and effectiveness of the conditioning process.

1. *Component Air Test*

   This test is performed on the single component, not inserted in the system. As explained, the diagnosis was set in cut-off phase, condition in which the lambda sensor should read an oxygen quantity equal to the atmospheric one.

   25 Lambda probes were tested. The test run for a total of 550 hours. The aim was to verify a shifting or decreasing of the electrical characteristic signal of the sensor.

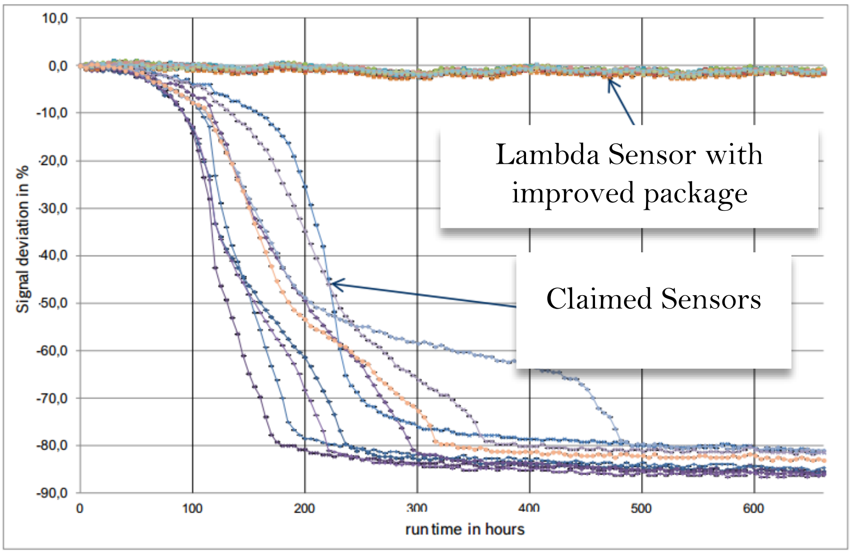



**Fig. 60** – Signal deviation in component air test

The graph (Fig. 60) shows the signal deviation of improved and claimed lambda sensor, in a test performed in humidity conditions. It is noticeable that after 550 hours of test the deviation remain almost unchanged. Goodness and effectiveness of the conditioning process are thus verified.

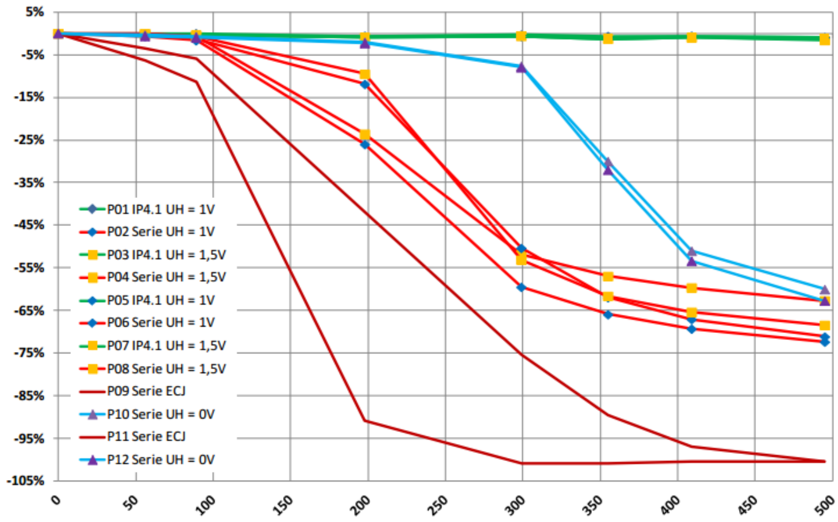



**Fig. 61** – Silicon poisoning test

A silicon poisoning test was also performed. From the trend shown in Fig. 61 is possible to verify that no deviation due to silicon occurred.

2. *Vehicle System Test*

Once air test was performed, it is important to test the component inside the system in which it will be inserted. The new design does not imply changes in shape, mounting position or anchorages. There should not be impact on the diagnosis set, or on the ECU dataset.

IVECO on diesel engines uses the function of Pilot Injections Calibration by Lambda. This function manages the injection of fuel in a precise way, according to the Lambda Probe signal. For this reason, it requires a highly accurate Lambda Sensor signal.

5 Lambda sensors were tested on vehicles in order to check system compatibility. In a first stage, vehicles run with the old sensor, and after a certain mileage, it was substituted with the new ones. During the test, several driving profiles were performed. These tests confirmed the neutrality of the introduction of the new design regarding the learning corrections of pilot-injections. Validation phase can be considered successfully concluded. The conditioning process can be considered an efficient and neutral solution for contamination and poisoning issues.

## 5.6 Eight D Report

| **8D REPORT – LAMDA SENSOR ERROR** | | |
|---|---|---|
| **D1** | PROBLEM SOLVING TEAM | Team Leader:<br>Team Members: |
| **D2** | PROBLEM DESCRIPTION | MIL on after complete warm up due to lambda Sensor error. The low oxygen measurement in overrun condition diagnosis is set. Problem occurs at low mileage (average 1000 km) on vehicles with Diesel engine. Lambda Sensor reads low oxygen and has slow dynamics. |
| **D3** | TEMPORARY CONTAINEMENT ACTION | Failed Lambda Sensor Replacement. 100% Produced component quality check in plant. |
| **D4** | INDIVIDUATE AND VERIFY ROOT CAUSE | Deeper analysis showed sensor lowered characteristic line pointing to damages and contamination of the sensing element. These usually came from:<br>• Lubricants or fuel additives/wrong fuel;<br>• Contamination of Silicones during EIO;<br>• Hydrothermal ageing due to low T and humidity.<br>These are due to a robustness lack of the component against contamination and poisoning |
| **D5** | IDENTIFY AND CHOOSE PERMANENT CORRECTIVE ACTIONS | Implementation of an improvement package to increase robustness against external poisoning and hydrothermal aging. Conditioning process applied. Higher number of three-phase boundary interfaces allows lower contaminants sensibility |
| **D6** | IMPLEMENT AND VALIDATE CORRECTIVE ACTIONS | Sensor specific test performed (Silicon Poisoning, Humidity) evidenced improvement greater than 90%. Vehicle test evidenced neutrality and compatibility of the improvement package with the system. |
| **D7** | TAKE PREVENTIVE MEASURES | The new package is applied to all production vehicles. Also other vehicle family will implement the new design. Test will be performed on other sensors, such as Nox Sensor, NH3 Sensor, in order to verify their robustness against contaminants |
| **D8** | CONGRATULATE THE TEAM | |

**Tab. X** – Eight D report

The 8D report is a resume of all problem-solving phases, starting from the phenomenon, till the corrective actions and problem resolution. It synthetizes the issue configuration and troubleshooting steps, in order to have a clear, organized and direct idea of the whole problem.

## 5.7 ACT: Lesson Learned

Lesson learned are experiences distilled from a project that should be actively taken into account in future projects. The European Space Agency defines lesson learned as:

"*A knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Lesson learned should be valid and applicable in that it defines a specific design, process, or decision that reduces or eliminates the potential for failure and mishaps, or reinforces a positive result*" [29]. Capturing lessons learned is an integral part of every project and serves several purposes. The lesson learned is a valuable tool for use by other project managers within an organization who are assigned similar projects. Lesson learned should not only describe what went wrong during a project and suggestions to avoid similar occurrences in the future, but it should also describe what it went well and how similar projects may benefit from this information [30]. Lesson Learned documents the cause of issues and the reasoning behind any corrective actions taken to address those issues. Lesson Learned should be thought answering to those questions:

- What was learned about the project in general?
- What was learned about what went well?
- What was learned about what did not go well?
- What was learned about what needs to change?
- What was learned about working with the customers?
- How was this incorporated into the project?

Answering these questions, one can obtain a horizontality of the experiences gained in a project. These experiences can be of a technical, managerial, communicative or applicative type.

The management of problem solving of a project is the most critical part to deal with. If new methods or solutions have been used, and have had positive feedback, it is a good approach to extend these methods at every level of the organization.

An example can be the WCM. This methodology was initially created to manage and organize plants, solving the biggest waste problems. WCM tools were then extended to every company level, such as logistic (WCL), administration (WCA), engineering (WCE) and quality (WCQ). The extension obviously involves tools modifications, which should not be used in a schematic way, but must be adapted to the context in which they are operating. WCM extension is a typical example of lesson learned implementation. No waste in time, money, and material are needed not only in plants, but also in each other company division.

Technical lesson learned extension, involves the application of new design solution to other products or field. Lambda sensor corrective action can be considered a technical lesson learned. In the case of problem solving addressed, the lesson learned results the contamination of external agents. Even if the problem was solved, it is useful to study also other vehicle family's sensor behavior, even if they did not evidence important issue or high issue frequency.

Other sensors are present in the ATS system, such as $NO_x$, PM, $NH_3$, that are subjected to the same contaminant agents. Even if their working operational mode and their characteristics are different from the lambda sensor, it is important to prevent any problem of the same nature, increasing their robustness.

An example of lesson learned report, is shown in the following.

| LESSON LEARNED REPORT | | | | |
|---|---|---|---|---|
| **Category** | **Issue Name** | **Problem/Success** | **Impact** | **Recommendation** |
| Design | Design Robustness | Lambda sensor showed failures due to contamination. Component robustness was low. | Company loss X $. No recall campaign needed, but several substituted items. | Always consider contamination in critical sensors |
| Process | Process change | Conditioning process to lambda sensor is implemented | The robustness of the sensing element is increased by 90% | Implement process change if element shows lack in robustness |
| Management | Problem Management | World Class problem solving methodology used in solve Lambda probe issue | The problem was solved in X days with success | Use the same approach to prevent similar issue occurrence |

**Tab. XI** – Lesson Learned Report

It is possible to notice that also the management approach must be extended. If the same problem occurs or should be prevented, in order to save time and resource, the same problem-solving methodology and tools should be used.

The lesson learned report is a document that must be shared inside the organization, and should be available to each company division. It is an integral part of the company, it adds experience that otherwise would be lost.

## Conclusions and Results

The aim of this paper was to adapt the methodologies of World Class Manufacturing and the Kaizen tools for the problem-solving phases of qualitative issues.

The practical case has been solved using these methodologies. The first step was to analyze the after treatment system's performance indicators of a light commercial vehicle, carrying out a cost deployment to assess the largest sources of waste. The oxygen sensor was found to be the most critical component to attack.

The problem-solving phase followed the PDCA procedure, applying the most useful Total Quality Management (Ishikawa, 5W1H, 5Whys) and WCM tools.

The meticulous description of the phenomenon represents a key point for the correct setting of the trouble-shooting phase. This stage has shown that an incorrect setting of the phenomenon leads to an excessive information dispersion that can divert attention from what is the real triggering cause.

The root cause has been identified efficiently and in short time. Corrective actions have been implemented only after discovering the true root cause, thus avoiding waste of time and money. Tests and validations confirmed the goodness of the corrective action, which can be considered a standard for the company.

The company has earned a lesson learned, consisting of an extension of the technical modification to other similar components, as well as a new problem-solving methodology. That methodology can be adapted also in other company's division, such as engineering, application, budget management, planning, testing, and so on, since has proved to be lean, intuitive and effective.

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