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Summary:

Nowadays, Quality has become a business qualifying feature. This is why many specific Quality Management Systems such as ISO 9001 have been developed all along the last decades. Nevertheless, ISO 9001 is considered by “Quality World Class” companies as “only” a good foundation but is not sufficient for them to reach their challenging operational targets. To seek Excellence, new systems such as Lean have emerged. The Quality part of Lean, usually named Built in Quality (BIQ) is regularly mentioned by researchers but no real synthetic model has been yet proposed to describe its characteristics. The present research work aims to contribute to fill this gap as it does not only depict what Built in Quality looks like but also proposes a synthetic original model detailing a “generic” Quality Management System for Lean Manufacturing companies.

Keywords ***(cf. Thesaurus du Management):***

MANAGEMENT

PRODUCTION

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PERFORMANCE

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2 Executive summary

Nowadays, Quality has undeniably become a business qualifying feature. This is why many specific Management Systems have emerged all along the last decades. ISO 9001 is the most popular of them. It provides some essential tools and organization elements to help companies to be competitive and credible in a Quality standpoint.

Nevertheless, ISO 9001 is considered by “Quality World Class” companies as “only” a good foundation. Unfortunately, it is not sufficient for them to target the ultimate state of Quality. To seek Excellence, new systems able to enhance manufacturing performances, such as Six Sigma or Lean have been developed by Motorola and Toyota.

The Quality part of Lean, usually named Built in Quality (BIQ) is regularly mentioned in the literature. Nonetheless, even if researchers globally describe its outlines, no real synthetic model has been yet proposed to describe its characteristics and guide practitioners to optimally implement it in companies already engaged in ISO 9001 types approaches.

The present research work aims to contribute to fill this gap. To do this, a relatively wide literature review has beforehand been performed. Then, an applied field research has been conducted in collaboration with a dozens of companies from various manufacturing sectors (most of them being considered as “best in class” for their Lean Manufacturing organization).

This paper does not only depict what Built in Quality looks like but also proposes a synthetic original model detailing a “generic” Quality Management System for Lean Manufacturing companies. Based on best practices examples, this research describes an optimal manner to enforce Built in Quality in a synergistic way with other processes and tools from, among others, Lean and Six Sigma in a global ISO 9001 context.

3 General Introduction

3.1 Introduction

Through the last decades, Quality has become a qualifying element for companies which goal is to be profitable in a sustainable way (Doucet, 2013).

Even if there are many definitions of what Quality means, the manufacturing industry is now considering Quality as having two sides:

- A classical one called “Customer Quality” and understood as being linked to the activities expanding customer satisfaction (conformity, performance…). This side helps the company to develop customer loyalty, to acquire additional market shares and, mechanically, to expand the volume of orders.
- An enlarged second one named “Internal Quality” that is dealing with improving the effectiveness of the company processes: not only the production processes, but also, for example, some others going from supply chain and process engineering to new products introduction or “Human Resources”. This side mainly helps to improve the profitability of the company and its ability to be cost competitive.

Both sides consequently improve the company ability to grow and to be sustainable.

ISO based Quality Management Systems, of course, tend to guarantee that companies are customer focused (analysis of customer requirements, treatment of claims…) and product Quality oriented (Quality controls, metrology…) but also globally “organized” (processes, procedures…) and looking for effectiveness through continuous improvement.

Despite the expansion of the ISO system, some additional systems such as the Business Excellence Models, Six Sigma or Lean progressively appeared to complete ISO gaps and go further in the way of Excellence and efficiency.

Mass production system, as developed by Henry Ford in the beginning of the twentieth century, requires a lot of capital, high levels of stocks, large quantities of space and an extreme standardization of products. It also results for companies in being not flexible to customer demand, not being able to drive changes easily and in a poor Quality level.

Lean manufacturing has been developed in Japan by Toyota (Toyota Production System, TPS) after the Second World War. Roughly, Lean can be considered as a response to the inconveniences of mass production.

The deep purpose of Lean is to fully answer to customer's ultimate requirements (and consequently make the company profitable and sustainable in the long run): to obtain the highest Quality, the lowest costs and the shortest lead times.

"Quality obsession" is a strong Pillar of Lean Manufacturing philosophy (Ballé & Beauvallet, 2013). The Quality side of Lean Manufacturing is often globally called "Built-in Quality" (BIQ).

3.2 Personal context

Having an engineering background, I have worked, in my seventeen years of professional career, in three different manufacturing companies: from a small French one (fifty people cold drawing company) member of an English group to a big one (Caterpillar France, two thousand people) part of a multinational group (One hundred thousand people).

Each time, I have deeply been involved in Quality Management: Process Engineering Manager in charge of Quality of new product introduction (QS9000 standard), Technical & Quality Manager and then Quality Division Manager.

During the three years I spent at Caterpillar France as Quality Manager, I have had the great opportunity to hold the position of Leader for the deployment of Built in Quality (BIQ). This position was critical especially as Caterpillar France was, at that time, pilot facility for the entire group with this approach.

Even if I was significantly experienced in Quality, I did not know anything about BIQ but had the chance that, fortunately, Caterpillar France has used the services of a consultant "Master" of TPS (Sensei) who participated in its original deployment in Toyota facilities in Japan.

3.3 Significance of the research

As we will see later in the literature review, many researchers and practitioners provided many information about the Quality part of Lean (often called Built in Quality or Jidoka) but only a few of them tried to go further to explain how this system can be integrated with other existing Quality Systems. Experts only obviously acknowledge that there is a strong link between Quality and Lean, that Quality is a bedrock of Lean and also that Lean is driving Quality. Literature is as well very helpful to independently understand the different tools and concepts of Lean but does not focus on Built in Quality as a whole and autonomous Management System in the context of pre-existing systems.

3.4 How the knowledge gap is being addressed

The purpose of this research is therefore to contribute to fill these Gaps by answering notably to some specific but relatively simple questions:

- What is the meaning of Built in Quality for manufacturing companies and how does it work?
- Can BIQ be totally or partially described trough an independent model or in a standard?

- Do manufacturing companies systematically require to implement BIQ to achieve their operational targets?
- Are there guidelines or best practices to deploy BIQ?
- Is BIQ complementary to ISO 9001 Management System or Six Sigma methodology in the journey to Quality Excellence? If yes, how manufacturing companies do manage and optimize the coexistence (or synergy) of those systems?

3.5 Scope

For convenience reasons, this study has been limited to:

- Manufacturing companies
- Production sites located in France
- The interview of French persons

Nevertheless, the scope of this research remains particularly large and rich as it includes a dozens of French and international companies of various sizes, most of them being world leaders in their business areas (Petzl for outdoor technical equipment or ARaymond for fastening and assembly solutions for instance).

Although located in France, many of those companies and manufacturing sites are unanimously considered as being "World Best in Class" for the practice of Lean Manufacturing in their own activity sector: Caterpillar France (machines construction) field, Schneider Electric (energy Management), STMicroelectronics (Microelectronic) and, of course, Toyota (Automotive Industry) for example.

3.6 Research Methodology

3.6.1 Introduction

Collis et al (2014) underline that the typical objectives of a research project are:

- "to review and synthesize existing knowledge
- to investigate some existing situations or problems
- to provide solutions to a problem
- to explore and analyze more general issues
- to construct or create a new procedure or system
- to explain a new phenomenon
- to generate new knowledge
- a combination of any of the above"

The following study is covering mainly three specific items of the list proposed by Collis et al (2014): it is firstly reviewing and synthesizing the existing academic knowledge through a focused literature review. Thanks to a qualitative exploratory approach materialized by a significant number of interviews and plant visits, it is investigating some real situations a selected set of companies are experiencing. Finally, through the analysis and the synthesis of all this practical knowledge, the final purpose of this research has been to construct and propose an original model.

3.6.2 Methodology

The first step (secondary data) of the research has been achieved mainly during the last quarter of 2015 due to a wide literature review job. This one has principally been performed not only through the reading of academic research and professional magazines articles but also thanks to the exam of reference books written by some of the most respected specialists in the fields of Lean and Quality.

In accordance to the conclusions of this review and especially taking into account the gaps thus revealed, a qualitative exploratory (primary data) research has been carried in a second time (first semester of 2016).

Key employees (Managers, Technicians, Team leaders and operators) of a selection of French manufacturing sites of companies having already in place an advanced Quality organization and having started (or completed) the implementation of "a form" of Lean Manufacturing have been interviewed. In order the structure of the interviews to be consistent enough, a standard questionnaire has been prepared and used as a guidance tool (see annex).

According to the content of the interviews and of the on-site observations, I have finally tried to sort out the best practices and to provide a clear picture through a synthetic model of what means the Quality part of Lean for those companies, taking into account their diversities.

3.6.3 Sampling

More than forty managers, team leaders and operators from eleven manufacturing companies have been interviewed and eight facilities visited.

As previously specified, all of those companies have two manifest common points:

1. They are all manufacturing oriented
2. All the manufacturing sites visited are located in France

Their sizes vary from 500 to 150 000 employees, they serve several industry sectors such as: automotive, fastening, electrical, connectors, trucks production, machines production, aeronautics, sport, microelectronics, and cranes production. They are part of a multinational group or from a family company.

These companies bring into play different kinds of manufacturing processes: from the most automatized to the most manual ones, from the most complex (large quantities of components used, lots of operation steps…) to the simplest (few components, few operations…).

The diversity of this selection is relatively relevant as it contributes to synthetically highlight similarities and differences in practices.

4 Literature Review

4.1 Introduction to Literature review

As previously explained, this study is dedicated to the Quality side of Lean and its integration with existing Quality systems in manufacturing industries. For this reason, the literature review has been divided into the following five distinctive parts. As we will deal with systems, Management Systems and integration of systems, a preliminary understanding of those terms is mandatory. Then, we need to acquire some knowledge about the meaning of Quality (its history, its main components…) and about the most commonly used Quality systems. Furthermore, we obviously need to conduct some global research about Lean: where it comes from, what its main features are, how it does work and what are the outcomes that could be expected subsequently to its implementation. In addition, it is also necessary to dig into the literature to appreciate how the Quality part is important for the success of a full Lean system deployment, what Lean means and how it is structured. Finally, we need to know the state of the research concerning the topic on the integration of Lean with other Quality systems such as, principally, ISO 9001 and Six Sigma.

4.2 Management Systems and integrated systems

As we will see later, Quality and Lean Manufacturing can be structured as Management Systems and be integrated in systems that are more global. This is why a preliminary understanding of the notions of Management Systems and integration of systems is needful.

4.2.1 Management System definition

According to Karapetrovic et al (1998), a "Management System" is the framework describing what managers will have to design and implement: this is a combination of a

set of processes and resources conceived to achieve a desired objective, such as, for instance, to create a product (see figure 1).

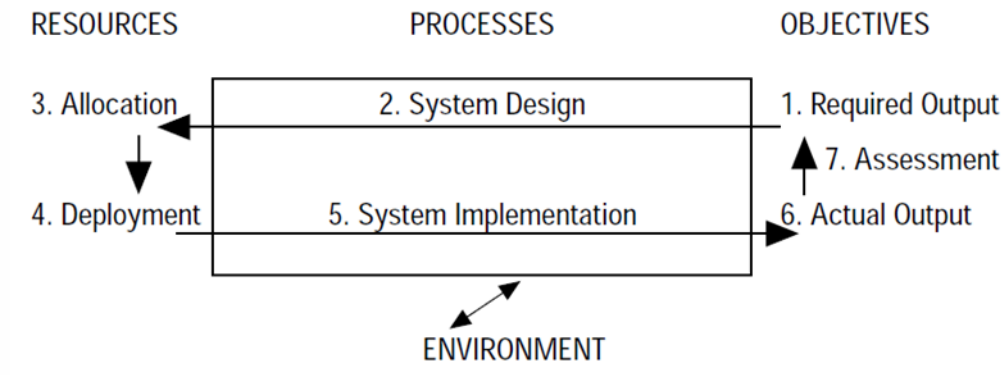

Figure 1 : Generic system "running" framework (Karapetrovic et al, 1998).

4.2.2 Integration of systems

An integrated system is a combination of two or more systems that results in the loss of independence of those ones and the creation of a more effective one by capitalizing on their advantages (Karapetrovic et al, 1998).

System integration will lead to the following benefits:

1. improved technology development, training and transferability
2. improved joined operational performance
3. improved internal Management methods and cross-functional teamwork
4. employees' motivation increase and reduction of the inter-functional conflicts
5. optimization of the auditing processes
6. reduction of costs (systems operating cost, maintenance, re-engineering)

4.3 Quality

4.3.1 Definition of Quality

There are many definitions for Quality in the literature. Nevertheless, the four following quotes provide a relevant summary of what is overall accepted from the more generic to the specifically manufacturing oriented ones.

ISO (2005) simply and “universally” defines Quality as the "Degree to which a set of inherent characteristics fulfills requirements."

Garvin (1988), for its part, provides one of most complete set of definitions he segmented into five distinct categories:

1. “Transcendent” definitions: those definitions are personal, subjective, constant and about concepts such as love and beauty.
2. “Product-based” definitions: Quality is considered as an objective and a measurable characteristic of the product.
3. “User-based” definitions: these definitions are dealing with customer satisfaction and are indeed individual and partially subjective.
4. “Manufacturing-based” definitions: Quality is simply perceived as being conformity to specifications.
5. “Value-based” definitions: Quality is considered as the ability to provide a good value for money.

Lillrank (2003) proposes a definition of Quality focused on the process side: “The Quality level of a process is defined by the amount of disruptions it is responsible of considering its tolerated zone of tolerance”.

Finally, Pyzdek (2003) defines Quality (for Six Sigma purposes) as “the value added by a productive endeavor”. Pyzdek also explains that there are indeed two kinds of Quality:

the current one and the maximum potential one, the difference between those two being called “waste”.

4.3.2 Quality Management System’s definition

The “official” definition of a Quality Management System proposed by ISO (2005) starts with the features of the Management System’s definition provided previously. Nevertheless, ISO significantly goes further especially by describing its required elements: “A Quality Management System (QMS) is a set of interrelated or interacting elements that organizations use to formulate Quality policies and Quality objectives and also to establish the processes that are needed to ensure that policies are followed and objectives are achieved. These elements include structures, programs, practices, procedures, plans, rules, roles, responsibilities, relationships, contracts, agreements, documents, records, methods, tools, techniques, technologies, and resources.”

4.3.3 Quality Management Systems Overview

Even if ISO 9001 is now considered as being a strong foundation notably as this system regularly dynamically evolved since 1987 (see figure 2), it is not enough by itself to bring superior results and to reach Quality Excellence as it does not really explain any clear methodology to do so (Doucet, 2013).

Figure 2: Evolution of ISO 9001 (Bureau Veritas, 2015)

During the last decades, new "tools" and "methodologies" such as Total Quality (TQM), Business Excellence Models (EFQM for example), Six sigma and "Toyota Production System" / Lean (see figure 3) emerged on the front stage and helped to complement ISO 9001 (Operational Excellence Consulting, 2012).

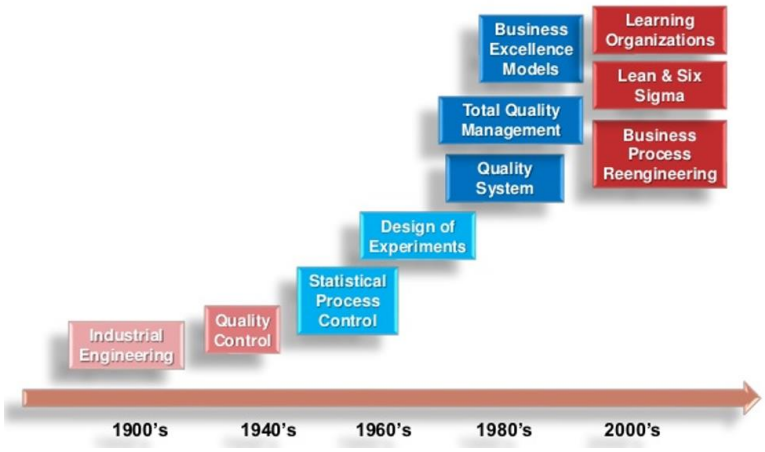

Figure 3: Evolution of Quality Management (Operational Excellence Consulting, 2012)

Those "Methodologies" not only supplement ISO based Quality Systems by providing a guidance and technical, organizational and cultural tools but also sometimes go widely beyond Quality to seek global Excellence.

4.3.4 Total Quality Management (TQM)

TQM is the generic designation for a systemic and broad approach of Quality Management. For example, ISO 9000 series Quality standards and Quality awards programs such as the American Baldridge National Quality Program (BNQP) or the European Foundation for Quality Management one (EFQM) are based on TQM principles (Westcott, 2005).

Westcott (2005) writes: "The philosophy of TQM can be summarized as a Management System for a customer-focused organization that involves all employees in continual

improvement of all aspects of the organization. It is an integrative system that uses strategy, data and effective communications to integrate the Quality discipline into the culture and activities of the organization."

Customer focus, total employee involvement, process centered, integrated system, strategic and systematic approach, continual improvement, fact based decision making, communication are the eight essential element of TQM (Westcott, 2005).

4.3.5 ISO 9001 Quality Management System

With more than one million of issued certificates in the world, ISO 9001's main purpose is to help organizations to ensure their customers to get consistent good Quality products and services. This standard is also used as a set of tools to rationalize and improve the efficiency of processes (Lazarte, 2015).

Kevin McKinley (ISO General Secretary) recently explains: "ISO 9001 allows organizations to adapt to a changing world. It enhances an organization's ability to satisfy its customers and provides a coherent foundation for growth and sustained success." (Lazarte, 2015).

ISO 9001 standard describes the requirements an organization's Quality Management System shall meet to potentially be third party certifiable. As previously explained and similarly to TQM, ISO 9001 standard is based on seven Quality Management principles: Customer focus, Leadership, Engagement of people, Process approach, Improvement, Evidence-based decision making and Relationship Management (ISO, 2015).

ISO 9001:2008 is consequently structured on five main chapters and rests on the PDCA continuous improvement cycle (see figure 4).

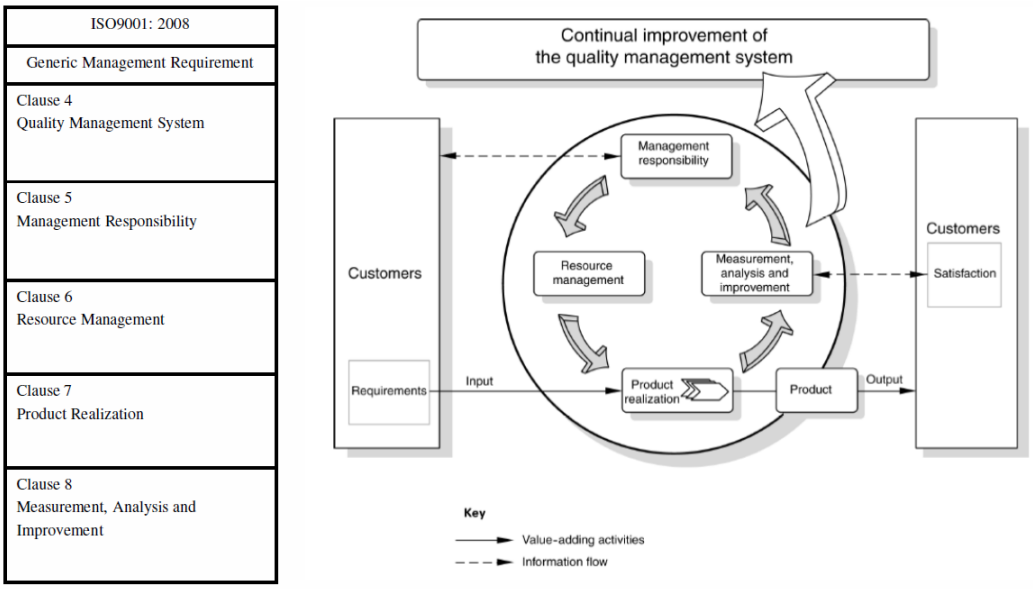

Figure 4: ISO 9001:2008 framework (ISO, 2008)

4.3.6 Six Sigma

According to Pyzdek (2003), "Six Sigma is the application of the scientific method to the design and operation of Management Systems and business processes which enable employees to deliver the greatest value to customers and owners".

Six Sigma was introduced by Motorola in 1986 and really started to be popular from 1995 when Jack Walsh, former General Electric CEO, integrated Six Sigma as a pillar of GE Strategy.

Six Sigma's purpose is to help companies to "make money" by significantly improving the level of Quality of their processes targeting a maximum of 3.4 defects per millions of opportunities mainly through the reduction of variations and suppression of wastes (Pyzdek, 2003).

Six Sigma is an advanced, powerful and proven "Quality" system based on the "belt" organization, the DMAIC methodology (based on PDCA – see figure 5) and a selected set of empirical and statistical tools (Pyzdek, 2003).

Figure 5: DMAIC cycle (Converge Consulting Group, 2015)

4.4 Lean

4.4.1 A brief history of Lean

In 1913, Henry Ford started the production of the famous T-Model. This is not only the first example of mass production but also an important step in the Lean history because it introduced the constructs of organized production continuous flow and of cycle time. The concept of continuous workstations allowed Ford to make throughput improvements by analyzing in details all of the production steps.

Just after the Second World War, Taiichi Ohno, a Toyota mechanical engineer, observed that the western production systems, designed for large scales production and economies of scales, suffered two major problems: they required a large inventory to run (high capital cost and poor Quality) and were unable to answer to the need of variety of the customers. Starting from the Ford system, Ohno worked on those problematics and progressively introduced “through his learning journey” during the next following decades many major concepts of what will be called later the Toyota Production System (TPS): small lots,

"Jidoka" (Built-in Quality), Kanban, Just in time… Shigeo Shingo, hired by Toyota in 1955 as an external consultant, developed the SMED methodology (Single minute exchange of dies) to balance the cost increase consecutive to the small batches production. Combined, those innovations led to the ability to produce a considerable variety of cars in relatively low volumes at a competitive cost (Holweg, 2007).

A strange feature of TPS is that it has not been formally documented at all until Kanban systems have been cascaded to Toyota suppliers in 1965. For this reason, the development of TPS has not been remarked for a long time. (Holweg, 2007).

Because of TPS, Toyota is, for a long time now, the indisputable reference in the industry in terms of Quality, production efficiency, reliability, sales and market growth (Spear, 2004) and, consequently, raised operational excellence as an industrial strategic weapon (Liker, 2004).

Even if many specific parts of Lean (Just in Time concept particularly) had already individually been studied and deployed before, the researches of the MIT International Motor Vehicle Program (IMVP), started in the early eighties, led to a first really complete and understandable picture of Lean.

Krafcik (1988), IMVP researcher, first introduced the term "Lean" in the paper "Triumph of the Lean Production System". He opposed "Lean" plants managed in the TPS way to "buffered" ones managed in the "recent Fordism" way. Thanks to the collection of data in thirty-eight worldwide automotive facilities, he demonstrated that Lean Production was superior in terms of productivity and Quality and that Lean implementation was more efficient than costly automated production lines. He also demonstrated that Lean methodology was not so effective only because of the specific Japanese culture but could be successfully applied in any country.

This article has been followed by the release of the IMVP famous book “The Machine that Changed the World” (Womack et al, 1990) that definitely helped “Lean” to start largely spreading in many industries all over the world. More recently, Liker (2004) wrote one of the most influential book about Lean dedicated to a large audience: “The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer”.

4.4.2 Definitions

As previously explained and as stated by Stone (2012), the term “Lean Production” has initially been introduced by Krafcik (1998). Then, Womack et al (1990) used it in “The Machine that Changed the World” to describe the manufacturing techniques, principles and philosophy developed during the last one hundred years by Toyota Motor Company and internally known at Toyota as TPS (Toyota Production System).

According to Bendell (2006), “Lean can be summarized as the systematic pursuit of perfect value through the elimination of waste in all aspects of the organizations business processes”.

Adams (2003) proposed a similar definition but opposed Lean to traditional manufacturing: “Traditional manufacturing philosophies stress high utilization of machinery and manpower with little concern for cycle time or manufacturing waste. The Lean manufacturing philosophy focuses on creating greater production efficiencies through maximizing value-added activities, while minimizing waste.”

Stone (2012) explains that there is often a confusion with the term “Lean” as it is indifferently used to name the four aspects of the manufacturing firm: operating philosophy, tools, activity and state of the manufacturer. He particularly proposed to use “Lean thinking” as the operational philosophy and “Lean principles” as the “tools used to execute”.

Rousseau (2013) summarized "Lean thinking" as doing the right thing, at the right place, at the right time, with the good quantity, minimizing wastes, remaining flexible and remaining ready for changes.

Additionally, Liker (2004) explains that TPS is not a toolbox or a set of Lean methodology made, for instance, of Just in Time, 5S or Kanban. He instead defines the "Toyota Way" as being a sophisticated production system in which all the elements contribute to help and encourage people to continuously improve the processes.

Jones (2014) asserts "Lean is not just another improvement methodology, but a very different set of behaviors and Management System". He regrets that Lean is often partially described and that, as key elements are missing, it cannot work successfully as a system and also insists that Lean is a "learning by doing" journey rather that a discipline that can exhaustively be learnt at school.

4.4.3 Waste elimination

Lean first focus deals with the obsession of the elimination of waste along the production flow. Waste is defined as being everything that does not bring any value added to the customer.

There are seven identified wastes according to Toyota's Production System (Pavnaskar et al, 2003):

1. Overproduction: Excessive amount of supply beyond the requirements of the following process.
2. Waiting: Lost time due to a disturbed production flow (lack of material, bottlenecks, "out of order" machines…).
3. Unnecessary transportation: Excessive movement of work in process material.
4. Over processing: Operations that do not add value for the customer.

5. Excess inventory: Excess of raw material, work in process or finished goods.

6. Excess Motion: Unnecessary movements made by the operators.

7. Defects: Production or rework of non-conforming parts.

In addition to those seven ones, Liker (2004) lately proposed a present time commonly accepted eights one:

8. Unused employee creativity: Lost opportunities due to underutilized employees capacities.

4.4.4 Lean systems and frameworks

4.4.4.1 House of TPS framework

The Lean (or TPS) House framework (see example figure 6) describes Lean as a holistic system of production principles (Netland, 2013). In the Lean house, the bedrock is made of stability (robust processes). It is made stable thanks to "Heijunka" (workload leveling), "Standardized work" and "Kaizen" (continuous improvement).

The first pillar is called "Just-In-Time" whose main purpose is to make each process providing the exact required volume using the right amount of resources at the moment requested by the customer. The second pillar's name is "Jidoka": it is mainly about Quality and is also often called "Built in Quality" (BIQ) or "Quality at the Source" (QATS).

The roof is dealing with the final goals of Lean that should lead to customer total satisfaction and company's long term sustainability: highest Quality, lowest costs and shortest lead times.

In many Lean House frameworks, people "engagement" (or "involvement") has been added: it materializes the high criticality of this factor to succeed with Lean implementation (Operational Excellence Consulting, 2014).

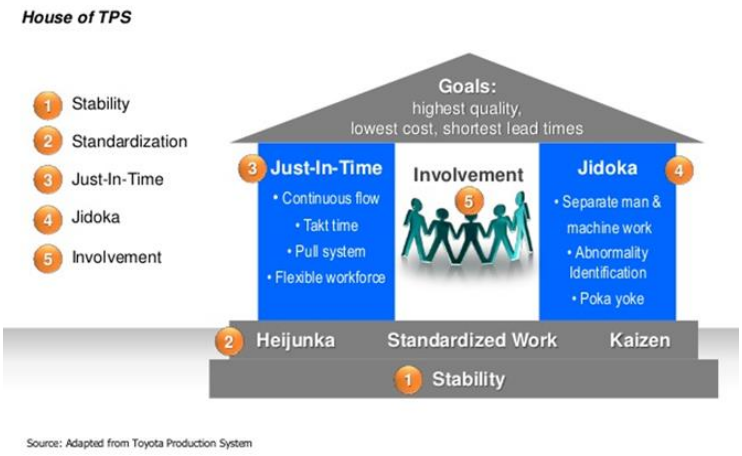

Figure 6: Lean Enterprise Framework example (Operational Excellence Consulting, 2014)

4.4.4.2 Abdulmalek et al framework

Abdulmalek et al (2006) provide a pyramidal framework of Lean (see figure 7). Lean System is described thanks to three categories: aims, guiding principles, and tools.

The deep purposes of Lean manufacturing system are cost reduction, Quality improvement, and lead times reduction. The three guiding principles are employee empowerment, waste elimination and use less to create more. In this framework, waste elimination is supported by the selective usage of the numerous tools of Lean.

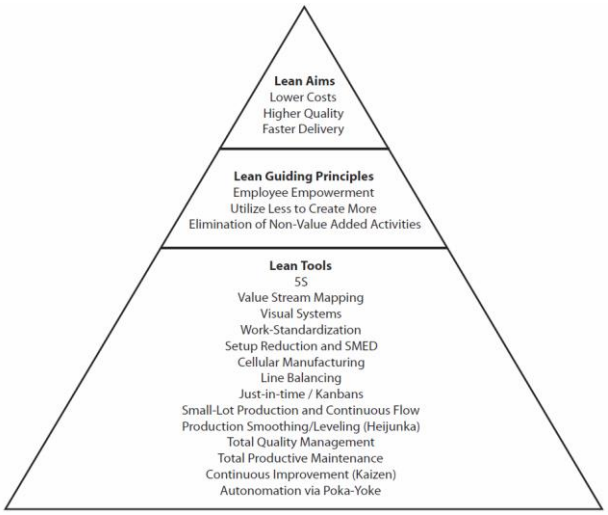

Figure 7: Lean Aims, Guiding Principles, and Tools (Abdulmalek et al, 2006)

4.4.4.3 Kumar et al framework

Kumar et al (2012) propose a very interesting sort of "cause and effect" "chronological" Lean implementation framework starting with the implementation of basic tools and finally leading to success (see figure 8).

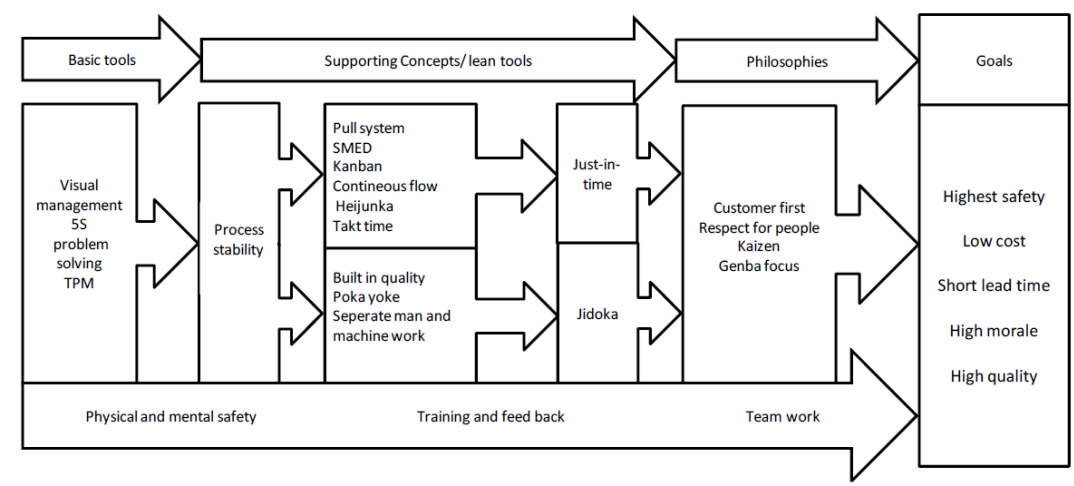

Figure 8: Lean structure (Kumar et al, 2012)

4.4.4.4 Liker's "4P" TPS framework

Liker's framework (2004) is probably, at that time, the most complete, influencing and applied model in the industry: a majority of company's own production systems are directly derived from Liker's Lean model.

This framework, schematically described in the "4P model" (see figure 9), is divided in four main sections and fourteen principles that are really clear and explicit.

Liker interestingly mentions that a large majority of the companies are only confined to a single level: the process one. He highlights that if the other three levels are not jointly implemented, the progresses will not be sustainable and those companies will absolutely never perform as well as the ones that adopted a true continuous improvement culture.

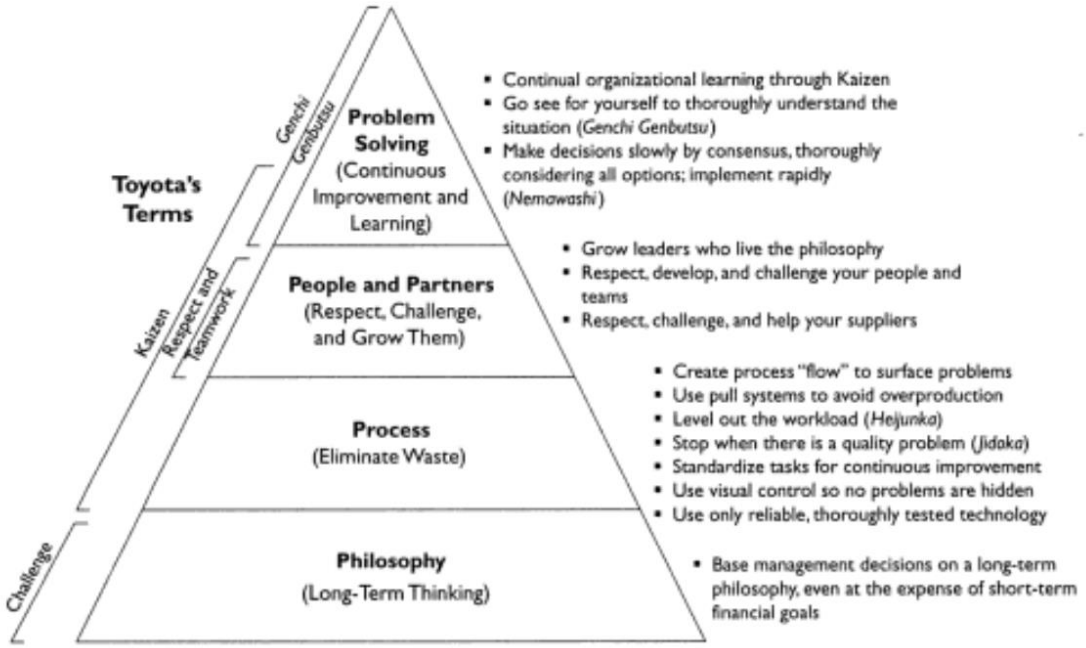

Figure 9: « 4P Model » (Liker, 2004)

4.4.4.5 Womack & Jones Lean approach

Womack & Jones (2003) have establish the list of the five fundamental principles of Lean approach:

1. Accurately determine the Value for each product
2. Identify the Value Chain related to each product
3. Establish the continuous value flows
4. Let the customer pull the value
5. Target the excellence

4.4.5 Outcomes of Lean implementation.

After some times, outcomes of Lean implementation are usually truly outstanding in the Quality, Velocity and Productivity standpoints. As an illustration, Roche (2013) provides some typical examples of outcomes associated to Lean implementation in different industry sectors:

- After three years in an aeronautic company: 30% to 99% of delivery accuracy and 80% of productivity improvements.
- At the end of the first year of implementation in a defense industry company: 90% decrease of the defect rate and 80% increase of the productivity level.
- After six years in an automotive company: 2400% improvement of the Quality level, cycle time divided by two, 300% increase of the capacity level and injury level decreased to zero.

Liker (2004), on his side, mentions the example of an American company producing industrial sensors. After a nine months' transformation led by the Toyota Supplier Support Center (TSSC), one of its production line greatly improved its operational performances: 93% of lead-time reduction, 83% drop of in progress inventories, 91% decrease of final products stocks, 50% reduction of overtime and 83% of productivity gains.

4.5 Quality part of Lean

4.5.1 Significance of Quality for Lean Success

Literature is very clear about this point: Quality obtainment is probably the most critical point for Lean success: it is not only an outcome of Lean dealing with waste reduction (Scraps, reworks….) but also a "must" preliminary requirement that makes possible the implementation of the other Lean principles (Just in time for example).

Åhlström (1998) highlighted that, in any Lean manufacturing transformation, Product Quality is not only a result (as, for example, inventory reduction will help raising problems to the surface that will be solved through Lean's solving methods) but also a prerequisite (as a Lean system will not work if the amount of scrap and rework is too high).

Ballé et al (2013) highlight that Quality is key in the Lean implementation process. The first reason is obviously because it is highly profitable to avoid scrap and rework operations. The second one is that Quality mastership is the heart of Lean as Just in Time cannot work if each production segment does not individually control its own level of Quality: the major prerequisite of Kanban implementation is that each part taken is good (to avoid continuous flow disruptions). To summarize, Ballé et al. state that the ability of the processes to perform right the first time is a very good metric for operational profitability.

Åhlström (1998) proposes a framework to explain which of the eight principles he defines as being key for Lean production (Elimination of waste, zero defects, pull scheduling, multifunctional teams, delayering, team leaders, vertical information systems and continuous improvement) have to be implemented in a parallel or sequential way. He concludes that, at the beginning, a strong effort must be exerted on the reduction of defects (see figure 10).

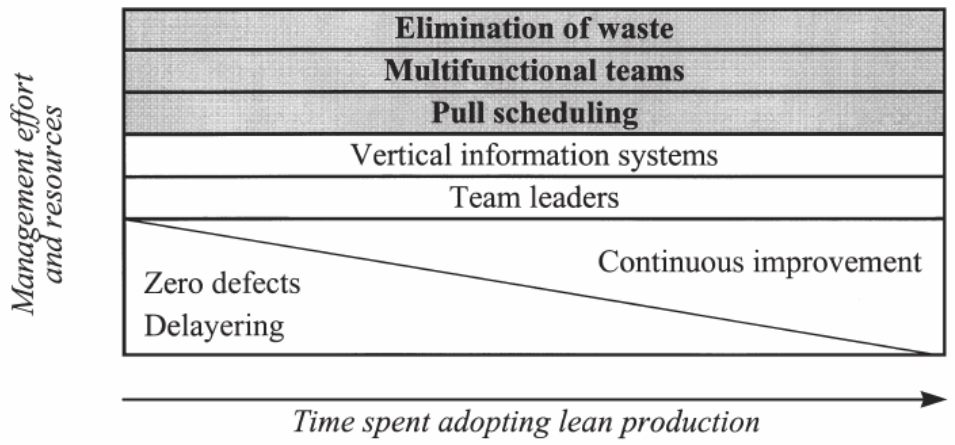

Figure 10: Sequences in the implementation of Lean Production (Åhlström, 1998)

Roche (2013) explains that during a Lean implementation process, problematics shall be approached in a certain order:

1. Provide employees the means to work in good conditions (safety, ergonomics, satisfaction…)
2. Uncompromisingly protect customers from Quality concerns
3. Control lead times
4. Reduce lead times
5. Reduce costs

If it is not the case, the effectiveness of Lean implementation could be affected and the results obtained not sustainable.

4.5.2 Built-in Quality (Jidoka)

Jidoka is the second pillar of the Lean House and is likewise called "Built in Quality", "control at the source" or "Auto-Quality" in the literature.

Ballé et al (2013) clearly explain the fundamental concept of "Built in Quality": each step of the process must be involved in "Auto-Quality" and strictly follow the three next principles: not accept bad parts from the previous process, not produce any bad part and not to pass any bad part to the following process.

Production teams must be autonomous and, in order to be able to only provide good parts to the next process, they need to consider the two following statements (Ballé et al, 2013):

1 Do right the first time by mastering the working process.

2 Be able to detect the wrong work in order to stop it before it goes to the next step.

Suzuki (2004) goes beyond and defines Jidoka as a sensor system that must detect and stop all the problems that obstruct the normal progress of Just in Time: not only the Quality issues but also the equipment's failures, missing parts or work delay.

Andon is not only one of the key tool of Jidoka but is over all the first step of the "built-in Quality" process: an alert must be activated each time the production line encounters a problem (Ballé, 2004). The consequences of this alert may vary from the immediate arrival of a supporting team to a full production line stop (in order the defect not to be passed to the next step without any decision).

Ohno (1978) highlights the importance of the usage of Andon saying that a production line that never stops can, perhaps, be either an absolutely perfect one or, most probably, a highly problematic one because, in this case, problems are willingly hidden and no improvement is indeed possible.

Roche (2013) mentions that the "built-in Quality" principle comes from the finding that, in addition to the company image deterioration, a defect is one hundred times costlier if it is detected at the customer level rather than after the first steps of tests. Roche also brings out that the intuitive human behavior often goes in the other direction: people act as if ensuring Quality was costlier than fixing non-Quality. Thereby, the first reflex when a problem is detected is to put the product aside to be able to continue to go ahead with the production.

Liker (2004) completes this opinion by explaining that one of the most difficult step during the implementation of Lean manufacturing is to make employees being capable to use the Andon as, culturally, employees understand that stopping the production lines is forbidden and is the most "dangerous" thing that can be done.

As a complement, Pegels (1984) insists also that operators have to be trained not only to control their own work but also the work of the preceding operations.

Those two dimensions are linked in a global and key learning process: the ability to detect the wrong work will allow the team to continuously improve its way of doing the job and, then, to progress in terms of competency (Ballé et al, 2013).

Finally, Ballé et al (2013) bring out that one major factor of success of "Auto-Quality" is linked to the company culture: employees will learn only if they feel plenty accountable for Quality by evolving in an environment of mutual trust where it is possible to share about defects without being blamed for them.

4.5.3 Problem Solving

Puvanasvaran et al. (2008) clearly identify employee's capability in Problem Solving as a mandatory prerequisite for Lean success (see figure 11).

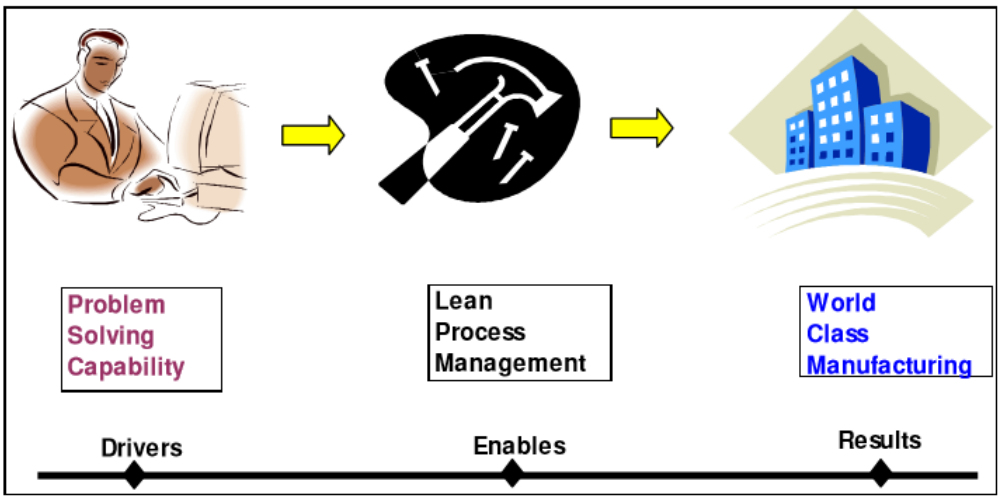

Figure 11: Illustration of Lean success model towards achieving World class Manufacturing (Puvanasvaran et al., 2008)

Ballé (2004) also points out this statement by quoting a highly revealing sentence derived from an internal document of Toyota released in 1973: "A foreman who stops the production line two or three times because of the same problem is not worthy of its function".

Jones (2014) drives the point by asserting that Lean is not based on experts using complex scientific methods but its success is, first of all, the consequence of the Problem Solving capability development of the first line of execution supported by a practical Management System.

Liker (2004) explains that the main parameter that made Toyota reaching such a level of Quality and excellence is probably the application of continuous improvement as a learning process. The organization shall learn from its mistakes by identifying the root causes, performing efficient corrective actions and providing employees the means to implement them. It shall as well develop an efficient transfer process that would guarantee this knowledge to be digested by its employees to become a competency and to be integrated in their future behaviors.

Ballé et al. (2013) provide a detailed description of the Lean Problem Solving methodology. They firstly insist that the methodology shall be applied on the shop floor with operators for mainly two reasons. First of all, it is easier to find the key elements as this is the place where the problems happened and, secondly, practice will help operators to learn and appropriate the methodology. Ballé et al. (2013) propose a methodology in eight steps supported by an A3 size sheet of paper:

1. Clearly identify the problem: what is the gap with the requirement that characterizes the problem?
2. Locate the primary causes by using the fishbone (5M) methodology.
3. Define the appropriate Quality level to reach after the problem will be solved (ppm target for example).
4. Analyze deeply the causes through the “5 why” methodology to really kill the deep root causes.

5. Express a few different corrective measures that could solve the problems before choosing the action plan strategy.
6. Implement the action plan.
7. Evaluate the efficiency of the action plan.
8. Verify that the results are sustainable and formalize the lessons learns.

Liker (2004) goes farther in the simplicity and describes the Problem Solving system used by Toyota Quality specialists and employees with only four "tools":

1. See on the shop floor what is happening
2. Analyze the situation
3. Use the one-piece continuous flow and the andon system to highlight the problems
4. Ask five times the question "Why?"

4.6 Integration of Lean and Quality Management Systems

4.6.1 Introduction

Liker (2004) seems not be convinced about the potential benefits that could bring the combination of Six Sigma and ISO 9001 to Lean Manufacturing in terms of Quality performance. He ironically describes the ISO Quality Management System as being a norm which preconizes detailed procedures with no evidence of effectiveness and Six Sigma as being a cumbersome system using complex statistic technics and monopolizing an army of project leaders.

Liker (2016) also mentions "Every time anyone at Toyota has been asked about ISO 9001 or QS 9000 when I was around they explain politely that they do not follow this process as they have their own Quality system that they believe in. The Quality system is PDCA leading to continuous improvement and learning".

Micklewright (2010), on his side, is convinced that ISO 9001 and Lean are complementary forces as the strengths of one system palliate the weaknesses of the other one. He particularly highlights, on one hand, that Lean makes continuous the requirements of improvements, provides tools to make improvements, clarify the need of waste reduction and encourages employee involvement. On the other hand, ISO is more detailed about improvement sustainability, requires training plans to be structured, requires documents and record control and is requiring risk analysis prior actions to be taken.

4.6.2 Integration of Lean in ISO 9001 based Quality Management Systems

Thanks to a nine years' data and information collection in 107 European companies, Chiarini (2011) observed that ISO 9001 certified companies considered as being "mature" in Lean Management (more than 3 years of use of the methodology) started to integrate Lean in their ISO system. He never mentioned any observation of a total integration but 98% of them integrated some Lean tools or principles in recorded documents mainly as procedures or work instructions. Nevertheless, Chiarini did not mention any formal integration at a higher level such as Quality policy or Quality Manual. According to those findings, Chiarini proposed some clear and interesting guidelines to integrate the main Lean tools and principles (Hoshin Kanri, Value stream mapping, Lean metrics, takt time, pull system, visual Management, commitment to Lean thinking, TPM, Kanban, ….) into the framework of ISO 9001. He literally rewrote the ISO 9001 text including the Lean concepts using only the terms "should" (when highly recommended) or "can/could" (in case of "nice to have" things).

The FDX 50-819 ISO standard (2011) also allows to make a link between ISO 9001 and Lean Management. It places the most adapted Lean tools in front of the chapters of ISO 9001.

Unfortunately, those two documents do not really propose a real model but only a kind of synchronization between ISO 9001 standard and Lean principles and tools (Bacoup et al., 2014).

4.6.3 Integration of Lean and Six Sigma

Snee (2010) argues that Lean and Six Sigma are complementary in the sense they are not targeting the same areas: Lean would be more focused on flows and Six Sigma on processes (see figure 12).

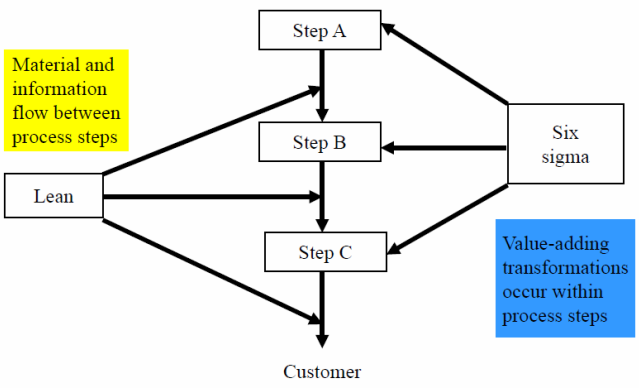

Figure 12: Improvement opportunities occur between and within process steps (Snee, 2010)

Snee (2010) defines Lean Six Sigma as being a project based methodology using not only Six Sigma but also Lean tools (see figure 13) and following the DMAIC methodology.

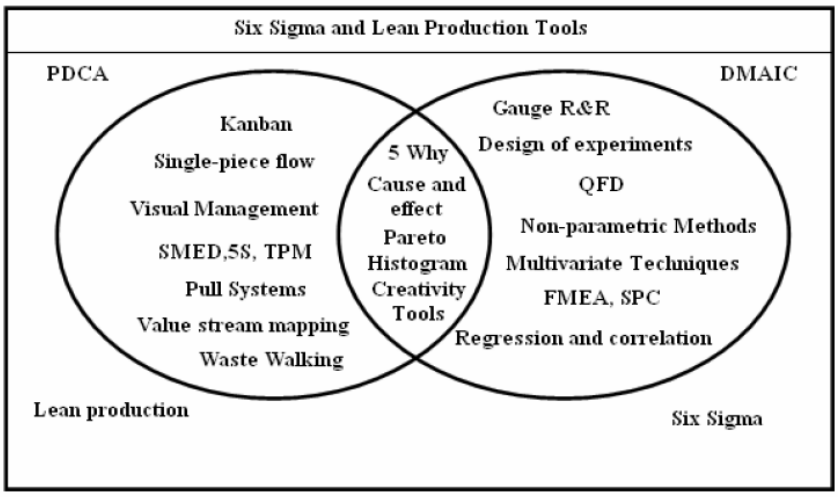

Figure 13: Six Sigma and Lean set of tools (Tohidi et al., 2012)

The model of integration Snee (2010) proposed (see figure 14) shows that Lean manufacturing and Lean Six Sigma are acting differently: Lean Management continuously drives the manufacturing system as Lean Six Sigma is surgically applied for the two types of improvement projects that could be either incremental or breakthrough ones.

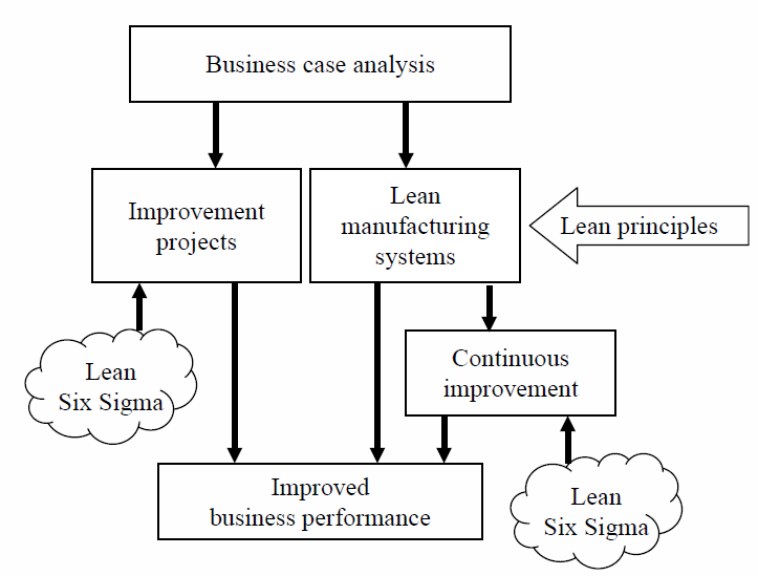

Figure 14: Integration of Lean manufacturing systems and Lean Six Sigma (Snee, 2010)

Pepper et al (2010) propose another framework to explain how Six Sigma and Lean are currently integrated and interact in the industry. By targeting the suppression of non-value added steps, Lean continuously improves the operational organization through a reduction of complexity. This process naturally leads to the identification of complex improvement opportunities that can then be addressed by "punctual" and "powerful" Lean Six Sigma projects (see figure 15).

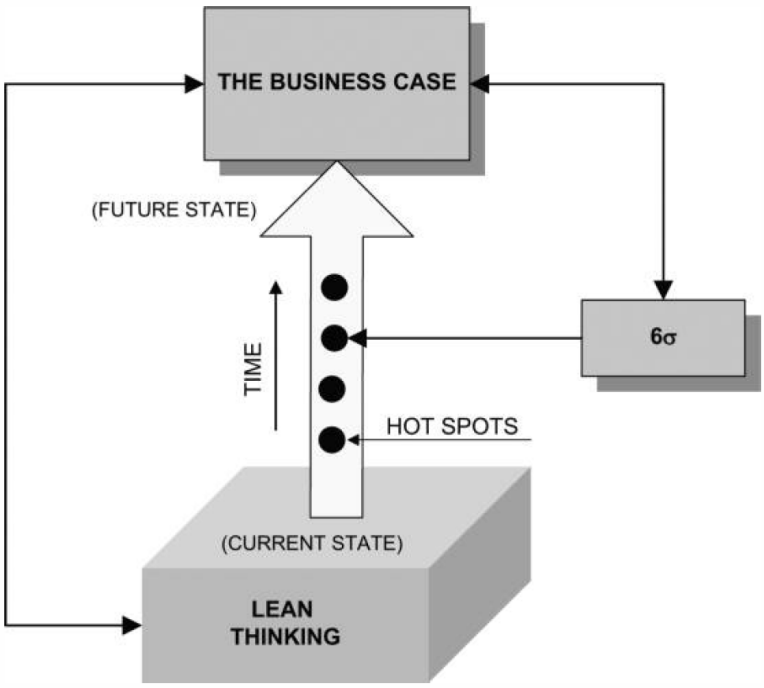

Figure 15: Conceptual model for Lean Six Sigma (Pepper et al, 2010)

4.6.4 Integration of Lean Six Sigma and ISO 9001 based Quality systems

Karthi et al. (2011) definition of Lean Six Sigma is a system based on the belt training and project Management organization, the DMAIC (Define, Measure, Analyze, Improve and Control) methodology and the Lean Six Sigma large set of tools.

They propose a new QMS standard named "L6QMS 2008" simply integrating the Lean Six Sigma features into the ISO 9001:2008 structure (see figure 16). To do this, they merely implanted the Lean Six Sigma structure into the frame of ISO 9001:2008 standard made of its five main clauses: Quality Management System, Management responsibility, Resource Management, Product realization and Measurement-Analysis-Improvement (see figure 17).

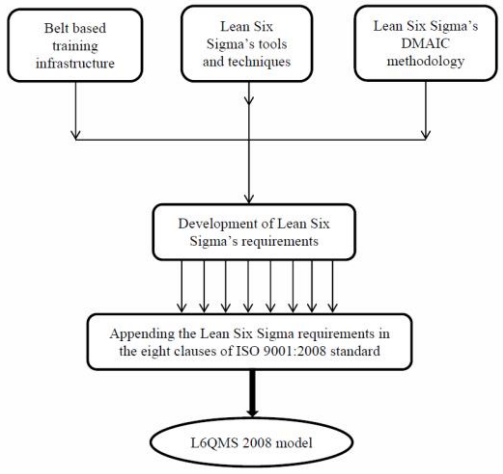

Figure 16: Methodology used to develop L6QMS 2008 Model (Karthi et al, 2011)

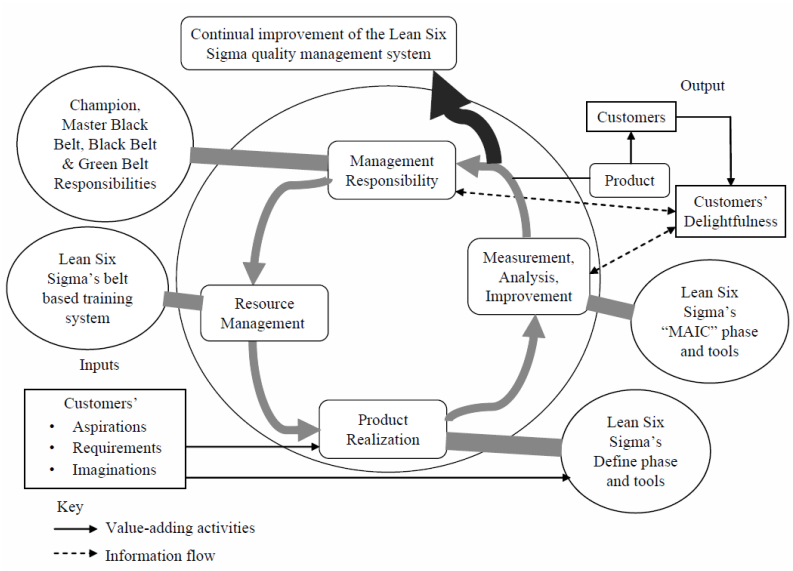

Figure 17: Model of process based Lean Six Sigma QMS (Karthi et al, 2011)

4.7 Literature Review Analysis

There is a lot of content about Lean in the literature as many academic investigations have been conducted during the last thirty years and as Lean has been a topic that has largely been exploited and developed by a profusion of consultancy firms.

Although the amount of data about Lean is huge, only a few researchers such as Womack, Jones, Liker and Ballé & Beauvallet have published synthesis volumes that are unanimously considered as references. Most of those authors are part of the Lean Global Network organization that includes sixteen local Lean Organizations leading the world of Lean.

The global features of Lean are pretty well documented in the literature. Even if there is no official standard relating what is Lean and how it must be implemented, authors seem to be pretty well aligned: Lean is a Management System that can be successfully applied in almost all manufacturing sector independently of the country culture, a successful Lean transformation nevertheless requires a significant company culture transformation, the key success factors have been identified (Teamwork, engagement, standardization…) and the "hundreds" of Lean tools (such as "5S", spaghetti diagrams, A3 sheet, Kanban…) helping to chase the wastes have largely and accurately been described.

Literature is relatively clear about the Quality side of Lean. It is really central in order Lean to be entirely successful. Quality is paradoxically both a prerequisite and an outcome of Lean Manufacturing. The Quality side of Lean is made of two distinct but connected parts: "Built-in Quality" and "Problem Solving". Literature enlightens that those two parts have to be employed as learning tools in so far as the continuous learning capability is a primordial factor for Lean success. Finally, authors firmly mention that

organizations shall focus on the Quality capability performance prior to start any action in the Supply Chain side.

The most important characteristics of "Quality at the source" and "Problem Solving" are comprehensively well depicted. Nonetheless, literature does not practically describe in details how to implement "Built-in Quality" in the day to day life. Even if some tools such as Andon or Poka-Yoke for example are well detailed, important features such as for example, Quality Gates, continuous learning process, team organization, escalation process and how those processes are working together are most of the time not plainly explained.

The "Problem Solving" process, for its part, is detailed in a good way. The different steps necessary to conduct a good analysis, the suitable tools to use (Fishbone diagram, "5 why" …) and the necessity of learning from the problems are clearly highlighted.

Unfortunately, Literature does not deeply advise us a lot on three significant themes: how shall be designed the data recording side of problem discovery and solving, how companies have to be structured to make the Problem Solving process effective and how organizations must proceed to integrate those processes in a sustainable way in their own culture.

The link between Lean and Quality organizations within a company is only confidentially treated in the literature. Surprisingly, and even if many articles are dealing with the particular case of Lean Six Sigma, only a handful of researchers worked on the possibility of creating a synergy between Lean and other Quality systems such as Six Sigma or ISO 9001 (even if, obviously, those systems largely share common features). There is no description on the way companies are (or are not) looking for efficiency between those

systems and, also, no synthetic academic guidelines available to make them efficiently work together.

5 Applied research

5.1 Production Systems deployment

Some of the companies I visited as part of this study (mainly the middle size ones and the ones at the beginning of their "Lean journey") started to implement the Lean concepts without designing their own structured Production System. Nevertheless, they have been, at the beginning and for most of them, guided by external consultants.

For their part, the multinational and multi-sites companies, most of the time, designed and implemented their own Production System. All of them are based on Toyota Production System and contain the principles, methods and tools described by Liker (2004) or described in the Lean House framework. Nevertheless, those companies often customized TPS for their own purpose to take into account the specificities of their business, culture or previous Management practices history. For instance, Schneider Electric included the Six Sigma methodology in addition to environmental and regulations requirements whereas Volvo Trucks not only integrated the "end to end" and the "integration" concepts but also industrial statistics as recommended improvement tools. ARaymond production System structure really takes into account its company values highly focused on people. Caterpillar, for its part, initially started with a "Liker like" structure but lately decided to increase the focus on the Built in Quality side according to the specificities of its business (complex machines requiring thousands of assembly operations of thousands of components).

Most of the time, Production Systems are based on an explicative booklet and have been deployed firstly thanks to a systematic campaign of trainings and secondly using regular assessments driven thanks to specific and detailed scoring rules made of a mix of tools implementations and operational results features.

As an illustration, here are quick descriptions of the production systems of four of the participating companies (Caterpillar, Schneider Electric, ARaymond and Volvo). It is to notice that, even if those systems clearly highlight some Quality concepts and tools, Quality (and, a fortiori, BIQ) is not, in most of the cases, explicitly described as a whole and as being an unavoidable pillar.

5.1.1 AAAAAA

Initially ISO 9002 certified in the middle of the nineties, AAAAAA started to implement the standardized AAAAAA version of TPS called APS (AAAAAA Production System) in 2006 after having deployed a Six Sigma organization six years' sooner. In a Quality standpoint, AAAAAA is now AAAAAA -QMS certified, AAAAAA-QMS being the AAAAAA "homemade" Quality Management System based on the latest ISO 9001 standards completed by some AAAAAA specific requirements.

APS is divided in three main subsystems composed of a set of fifteen principles:

- **Operating System**: Validate our processes, Drive standard works, Pull, Even the load, Make value flow, Chase waste.
- **Cultural System:** Put safety first, Stop to fix, Take the customer's view, Develop people, "Go, see and act".
- **Management System:** Act decisively, Make it visual, Align the targets, Actively listen.

From around 2010, AAAAAA local facility has been volunteer to be pilot facility for the deployment of a second step of Lean boosted by the European Facilities Group President and specifically guided by a "genuine Toyota" highly experienced "Sensei" trough regular coaching sessions. According to the great success of the experience (AAAAAA local facility received the Corporate Award of Operational Excellence two consecutive

years in 2014 and 2015), this additional system has been deployed in all AAAAAA facilities by the newly created AAAAAA Enterprise System Group (AESG).

The system is described by AESG (2014) as follow: “Lean is AAAAAA’s disciplined execution to eliminate waste and drive efficiencies and is built on a strong foundation of Six Sigma and the AAAAAA Production System (APS).”

5.1.2 BBBBBB

BBBBBB also built its own production system called Schneider Production System. BPS has three main goals

1. Improve safety, Quality, Service Level and productivity in the Schneider Electric Worldwide facilities.
2. Optimize the capital employed
3. Engage the employees

It is organized around three axes:

1. People commitment: 5S, Lean Manufacturing (mainly chase the wastes), Short Interval Management, Suggestions System.
2. Product/Process engineering: Kaizen, G8D, Six Sigma, SMED, Poka-Yoke
3. Management of industrial and logistic processes: Provision of components, work in process Management, Customer orientation

Those three axes are supported by forty detailed principles.

5.1.3 CCCCCC

CCCCCC designed its own system called CTOMS (CCCCCC Total Operations Management System) in 2013.

It is made of seven elements organized in two categories:

1. Enabling elements: Total Quality, Process Optimization, Workplace Management, Flow Management
2. Sustaining elements: Strategy deployment, Leadership & organization, People Engagement.

Those elements are supported by a set of around forty selected tools and methods. Those ones are driven by a selection of seven key performance indicators dealing with Quality, delivery performance, employee's engagement and continuous improvements.

5.1.4 DDDDDD

DDDDDD borrows the symbolic of the "house of Lean" to describe its Management System (DPS). It is made of a basement (Management commitment) and five pillars (Performance Management, People development, Improvement Structure, Lean Practices and end-to-end alignment). DPS is seeking three main goals: Customer satisfaction, Business Results and Employee Engagement. Those six pillars and basement are supported by twenty elements.

5.2 Definition of Quality and impacts of non-Quality

The way manufacturing industries understand Quality is very pragmatic and seems to be attached, at first sight, to the product they manufacture. This contributes to understand what ultimate goals they are expecting from a Quality Management System.

The unanimously accepted definition of a "Quality product" can be summarized as follows: "a functional product that meets specifications, made with the right process and the right components".

Furthermore, for a large majority of the managers I discussed with, the consequences of non-Quality problems are listed below and have a more or less important weight depending of the specificities of their company:

1. Unsatisfied Customers (nonconforming product or nonfunctional detected by the customer) causing losses of market shares.
2. Scraps (of non-conforming product detected internally) causing losses of profitability.
3. Reworks (of non-conforming product detected internally) causing losses of profitability (and often increased customer risks linked to the realization of those "out of standard process operations").
4. Production flow disruptions (chain stops, exhausting emergency Management ...) causing losses of productivity.

5.3 How Lean manufacturing companies deal with Quality (Quality part of Lean)

5.3.1 Introduction

"Built in Quality is the foundational Lean principle

1. to evaluate the acceptable Quality level of any process (good or bad)
2. to stop a defect from being passed to the customer (next process)
3. to describe the problem, sort and provide feedback to the causal area
4. process owner to determine the root cause of the defect and to fix the broken process that caused the defect to prevent it from recurring
5. process owner to implement root cause analysis and provide feedback to impacted customer

The goal of Built in Quality is to stop missed defects and achieve zero rework in all processes throughout the extended value stream".

This is the example of how one of the multinational company involved in the study (using complex manual assembly processes) synthetically defines the Quality part of Lean it calls “Built in Quality”. For them, BIQ is the “foundational Lean principle”.

Two goals (giving a clear idea about the metrics companies will follow to monitor BIQ) are assigned to BIQ:

1. “To stop missed defect”: it means that BIQ shall ultimately improve the production and detection processes so that zero defect can leak and affect customers (internal or external).
2. “Achieve zero rework”: this second item is focused on the efficiency of the processes and means that, finally, the processes must be robust enough to make good the first time.

Even if they are diverse, the companies involved in this study can be divided in three categories according to their type of production processes (see figure 18): simple processes, highly automated ones and, finally, complex highly manual ones (see table …). Each company of these categories do not feel the need of building the structure of their Quality Management System in the same way: some will not use any specific Lean Quality Management tool; some will use them with a clear distinction for the manufacturing side (autonomation or Quality at the source). Some others will only use a selection of secondary Quality Lean tools used in conjunction with a Problem Solving methodology (more or less powerful) and non-Lean Quality tools such as SPC, AMDEC or Six Sigma depending of their needs.

In fact, the two main variables seem to be:

1. The complexity level of the processes and supply chain that will significantly increase the quantity of potential defects and then act on the powerfulness level requirement for the Quality Management System and tools used.
2. The level of automatization that will lead to the use of a significantly different set of Quality tools for highly automatized and for highly manual production lines.

Types of production processes	Details	Visited Facilities concerned	Quality issues opportunity amount	Potential impacts of Quality issues	Main Lean Quality management tool used	Secondary Lean tools used involved in quality outputs	Lean/Non Lean quality tools used	Non Lean quality tools used
Simple processes	Low quantity of components, low number of tasks	1	Very low	Low (reaffection of people)	None	Standard works, Autonomous production team, Short interval Management	Problem solving methodology	AMDEC
Highly automated processes	Automatic production lines integrating automatic controls with no human intervention	2	From low to high	From low to high	Autonomation (Man/Machine separation)	Standard works, Autonomous production team, Short interval Management, Kaizen, Escalation	Problem solving methodology	SPC, AMDEC
Complex highly manual processes	Long production lines involving a lot of operators, thousands of tasks, hundreds of components	5	High	High: productivity reduction (production line breakdown), costly reworks, impact on end customer…	Built in Quality	Standard works, Autonomous production team, Short interval Management, Kaizen, Escalation	Problem solving methodology	AMDEC, Six Sigma (2 on 5 companies)

Figure 18 : categories of processes and associated quality tools requirements

5.3.2 Operational Quality Management System of Lean companies and Built in Quality Model

Figure 19 synthetically describes the operational Quality Management System of the most advanced Lean manufacturing companies.

This Management System is composed of a core part that is what Lean companies name “Quality part of Lean” or, more commonly, “Built in Quality”, of Quality processes that are usually not considered as Lean inherent and is supported by some other general Lean components.

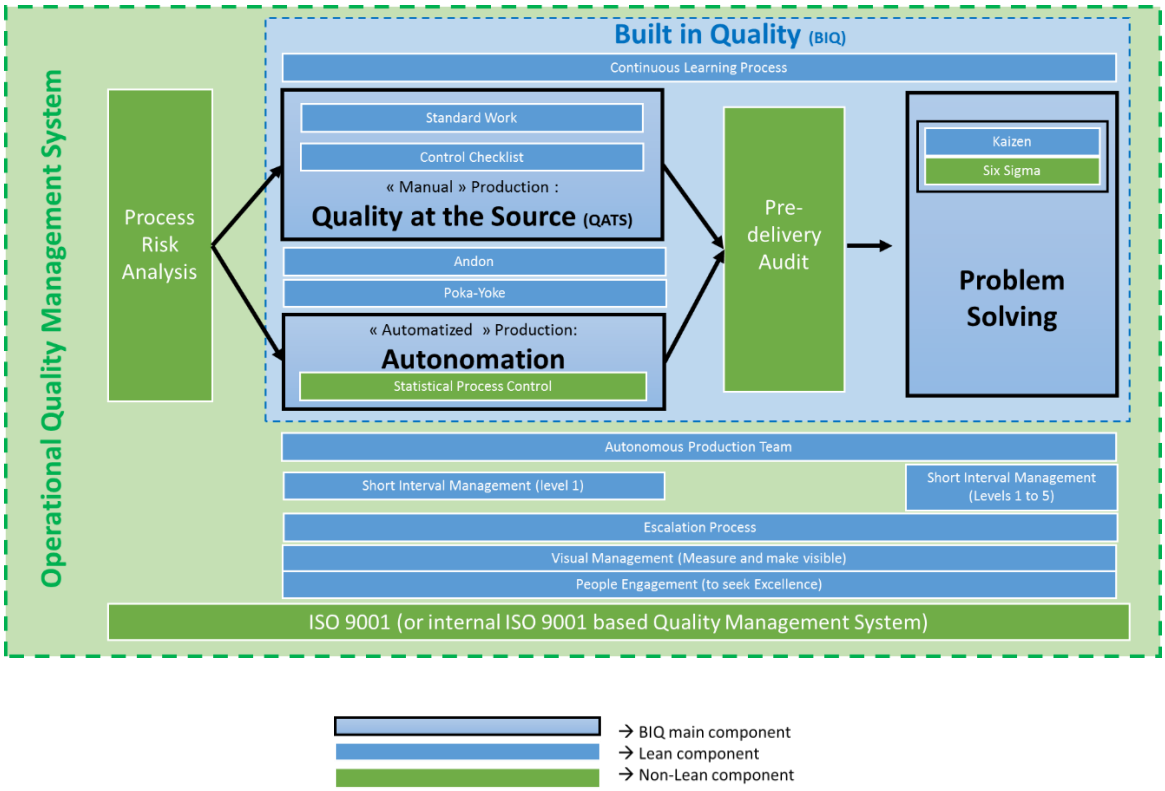

Figure 19: Operational Quality Management System of Lean Companies

In this study, as it is the case in the majority of the companies visited, Built in Quality (BIQ) is the term used to designate the Quality part of Lean. In other words, BIQ is aggregating all the Lean tools, concepts and processes that contributes to reach a superior Quality level. It does not only stand for the reactive operational Quality side of Lean as sometimes described in the literature. In this paper, this specific part will be called Quality at the source (QATS).

5.3.3 Lean Operational Quality System description

The core part of this system (BIQ) is made of three main sub-systems:

1 **Quality at the Source (QATS)** is mostly dedicated to the operation part of "manual" processes. QATS is used in symbiosis with the **Standard Work** and the **Control Checklists** Lean concepts.

2 For "automatized" processes, the concept of **Autonomation** is used instead of QATS. It is usually applied in conjunction with a non-Lean tool called **Statistical Process Control** (SPC).

Andon, Poka Yoke, both being original Lean concepts, are transversely supporting the BIQ and Autonomation Systems.

3. **Problem Solving** is the third pillar of this System. **Kaizen** and **Six Sigma** (DMAIC methodology particularly) do efficiently support this process (especially when the extent of the problems starts to be significant). The five levels of the **Short Interval Management** (SIM) process are continuously and intimately interacting with the Problem Solving process.

Upstream of QATS and Autonomation, the most advanced companies systematically use Process Risk Analysis tools in order to prevent issues potentially linked with changes (new products or processes introduction, products or processes change …).

Between BIQ/Autonomation and Problem Solving, a **Pre-Delivery Audit** (PDA) is generally performed. The purpose of this audit is of course not to catch all the defects of the products but to verify that all the process of BIQ and Autonomation dedicated to stop the defects are constantly running in an effective way without drifting.

From QATS/Autonomation to Problem Solving, a series of processes imperatively requires to be in place in order the entire Quality System to really perform at a high level. The **Autonomous Production Team** as well as the **Short Interval Management** components that will drive all the BIQ processes need to be preliminarily implemented. The **Escalation** and **Continuous Learning** processes, the **visual Management concepts** and the **Engagement** of the employees are mandatory for the system to be sustainable.

Finally, **ISO 9001** (or any similar QMS) is covering all the system as a strong bedrock. It brings in particular the basics of Quality culture (continuous improvement, Management engagement, effectiveness and efficiency, Customer focus, Risk Management for instance) and makes basics but necessary processes to run (audits, metrology, records and documents Management for example).

5.3.4 Built in Quality maturity level of the facility visited

Figure 20 provides a picture of the Built in Quality maturity level of the eight manufacturing facilities visited in the framework of this research.

This picture cannot obviously be considered as being perfectly objective because it is based on visits that only last from a half to one full day and has been raised at the sole appreciation of the author. Nevertheless, it provides a comprehensive idea of the diversity and richness apprehended during this applied research phase.

Level of implementation and effectiveness	Not Applicable	Not implemented	Implementation in progress	In place but not fully effective	Fully effective
Process Risk Analysis	0	0	2	1	5
Autonomous Production Team	0	0	0	0	8
Standard Work	4	0	0	0	4
Control Checklist	4	0	2	0	2
Quality At The Source	4	2	0	0	2
Autonomation	3	0	0	2	3
Statistical Process Control	3	0	0	3	2
Andon	0	0	1	3	4
Poka Yoke	0	0	0	2	6
Short Interval Management L1 to L5	0	0	0	2	6
Continuous Learning Process	0	0	3	1	4
Escalation Process	0	0	2	1	5
Visual Management	0	0	0	3	5
People Engagement	0	0	0	0	8
Pre-delivery Audit	0	0	1	1	6
Problem Solving	0	0	3	0	5
Kaizen	0	2	1	2	3
Six Sigma	0	4	1	1	2
ISO 9001	0	0	0	0	8

Figure 20 : Levels of implementation and effectiveness of Quality tools, processes and systems of companies visited (number of companies)

5.3.5 Quality at the source (QATS)

5.3.5.1 QATS description

More generally, the Quality at the source methodology is commonly implemented in large production lines simultaneously involving the action of several humans dealing with several components and several manual operations. In this particular case, the risk of problem opportunity is elevated considering the high complexity of the process and the constant intervention of the human being that could be source of mistakes. For example, among the companies I visited, QATS is used, of course, by the automotive industry companies but also by the companies involved in similar businesses (production of trucks or construction machines for instance).

In all of those facilities, QATS is pretty much described in the same manner and involved:

- A 100% “in process” control (auto-control) manually performed by operators or automatically by automated devices
- Quality Gates dedicated areas where inspectors verify that the previous operations have properly been correctly performed on 100% of the products
- A final control that simulates what the first actions the customer will perform when he will receive the product (pre-delivery inspection, PDI)
- A longer and more detailed pre-delivery audit usually performed by high skilled technicians which purpose is to confirm the effectiveness of the previous controls

The purpose of this control organization is to stop Quality issues as close as possible to its creation point in order, of course, to protect customers for any disturbance but also to

allow the organization (production operators and also controllers) to continuously learn from its mistakes trough an immediate “feedback loop” system.

For example, when a Quality Gate inspector detects a defect, he will immediately activate the Andon process and inform the team leader (see paragraph 5.3.7) of the section responsible for the creation of the issue. This one will, at least, immediately check the in process products (and, if needed, the stock of final products wherever it is located) to be sure they have not been affected by the problem. He will also inform the operator responsible and lately (usually during the SIM meeting) the whole team. Sometimes and when the duration of the takt time allows it, the Quality Gate inspector will directly go to the operator’s workstation to explain him, face to face, what he discovered. This way of doing is not a bad one as it really allows the inspector to be considered by the operators as being part of the team and not just as “a cop”. The operator will theoretically learn from its mistake and naturally modify its “behavior” in case of an incorrect application of the standard work. If the problem’s cause is different (inefficient process, defective tool, defective “raw” material for instance), the Autonomous Production Team will eventually immediately implement interim corrective actions (ICA) (sorting, additional controls or operations…) which target is to simultaneously allow the continuity of the production and to assure the protection of customers during the time a less costly and less painful solution (PCA, permanent corrective actions) is found by the support services (engineering, process engineering, maintenance, supplier Quality department…) through the Problem Solving process. Figure 21 schematically describes how the QATS process works.

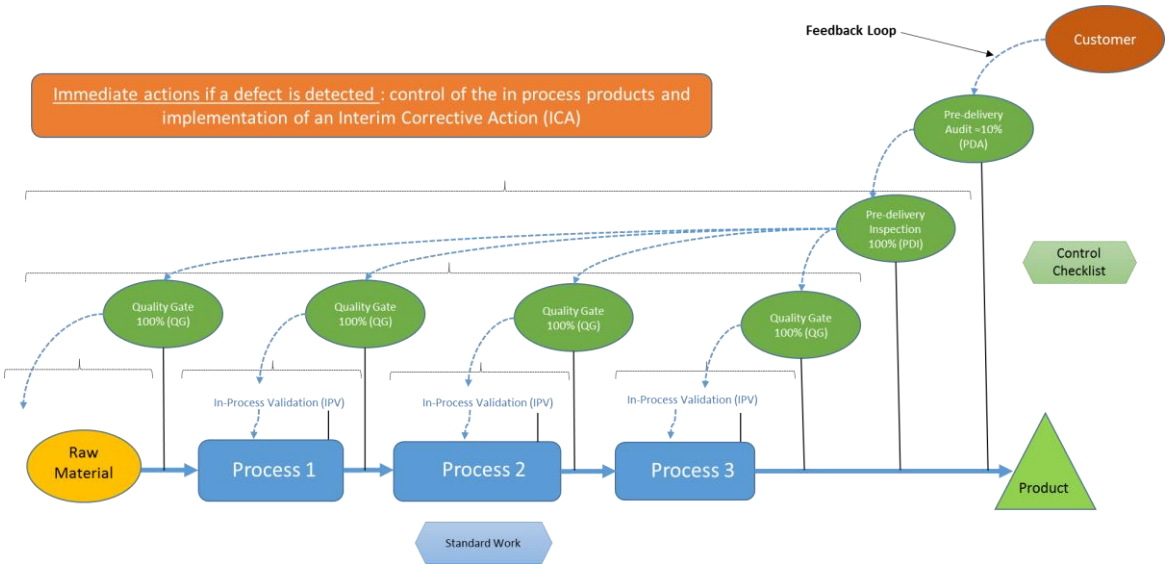

Figure 21: Schema of the Quality at the source process

5.3.5.2 Quality at the source key success factors

For this process to be effective, the companies I met told me that some points are very important:

1. It is greatly better that the Quality Gates, PDI and PDA operators are hierarchically not linked to the production organization to avoid any conflict of interest.
2. All the issues shall be recorded and affected to a responsible (production line, process engineering, engineering, suppliers …). Continuous improvement targets have also to be assigned to each of them. All those data have to be largely visible in all the organization and, of course, require to be regularly reviewed at all levels but mostly at the top Management one. These measures will allow everyone in the organization to better feel responsible for the pain felt by the production line.

3. All the controls must always be performed in accordance with the requirements of a checklist and not be dependent on the sole discretion of the inspector or of the operator.
4. Each item of the control checklists needs to be very specific (thanks to a picture showing the item to check for example) and accurate (thanks to the indication of a measure range or a go/no go feature for example). A fuzzy instruction such as "Check that there is no oil leak around the machine" is not acceptable for instance. To sum up, each item of the checklist shall absolutely and unambiguously answer to the following three questions: what to check? How to check? How to judge?
5. The quantity of items of the checklists needs to be limited in time to the cycle time of production. If there are too many items, some controls will not be properly performed or not be performed at all. In this case, the inspector would not be considered as accountable as the Management did not provide him the conditions to make his job in a proper way.
6. Two kinds of checklists can be established: a permanent one and a dynamic one. The purpose of the dynamic one is to include temporary items linked to defect that have recently been found in order to be sure the interim corrective action does well protect the customer. Those items will be removed when the effectiveness of the permanent corrective action will be demonstrated.
7. The checklists (that can be under a paper or data format) must be individually signed by the inspectors (by the operators when it is about auto-control). It is even better if each item is individually checked. This is one of the actions that helps making people accountable for their job and make them feel that what they do is important.

8. Checklists (even permanent ones) can be lighten if the items are simultaneously demonstrated as being statistically 100% “under control” and if their severity would not be catastrophic in case of occurrence.
9. An additional review of the issues detected during a working day needs to be performed during the SIM meeting at each shift at the Autonomous Production Team level. This will allow all the operators to learn to avoid to make the mistakes but also to be able to detect them if they are in front of their eyes. The capacity of detecting a defect is, as least, as important as the capacity of not creating an issue.
10. Three categories of defects have to be considered and differentiated:
    - Defects that have been created and then detected at a control step (“found defect”)
    - Defects that have not been detected by a previous control stage but should have been detected as they were explicitly detailed in a control checklist (“missed defect”).
    - Defects that have not been detected by a previous control step but was not clearly expressed in the control checklist (“new defect”).

    The discovery of a “new” defect shall never be considered as a fault (at least at the Autonomous Production Team level) but as an improvement opportunity. Nevertheless, the “found” and “missed” defects must be very seriously taken into account by the team for two main reasons:

    - Most of the time, they are the result of a bad application of the standard work, a bad reading of the control checklist.
    - Those defects reach the customer and make him feel a certain amount of pain.

Those three categories need to be recorded separately and the evolution must be monitored. In theory, the quantity of "found" and "new" defects should be high at the beginning (each time there is a "change": new product or process introduction). The amount of "new" defects should then rapidly decrease as they are now included in the control checklists. Then, according to the continuous learning process mainly driven by the feedback loop, the quantity of "found" and "missed" should go down continuously.

5.3.5.3 QATS limitations

Even if it is a very effective process, Quality at the source is not utilized in all the companies. Facilities using simple processes (with a limited number of operations and using a limited quantity of components) and highly automated processes do not systematically know what the Quality at the source concept is. They seem not to be concerned by the potential benefits that it could bring mainly because their processes are not sensible enough to Quality issues. The quantity and the severity of Quality issues that could affect the efficiency of the process or the satisfaction of its customer (external but also internal) is not significant enough.

For example, one of the company I visited produces small batches (around 30 to 150) of small components using around three to five components with three to five assembly operations performed by a single person in a single piece flow process. This person also performs the Quality and functional controls by itself. This kind of process does not require the QATS process to improve according to the company mainly because it is very simple, it does not involve several operators and because it includes the functionality controls. Moreover, they explain me that the customer Quality level was very closed to

the perfection. So, as the process demonstrated its continuous efficiency and effectiveness, no need of additional customer protection or continuous improvement.

Another company produces electric components in a fully automated line including assembly and brazing operations using a limited number of purchased components. There is no human activity from the beginning to the end of the process: the components are automatically selected by the machines according to the production plan and all the possible controls (vision, SPC, functional, Poka-Yoke) are automatically performed by the machine. If a part fail to pass one of the test, it is rejected and analyzed later unless the quantity of rejected parts is higher than a predefined number. In this case, the machine is automatically stopped and calls for a human action. This type of process is a typical example of application of the autonomation concept (see paragraph 5.3.6) strictly separating the man and the machine. Obviously, it does not require any QATS process as no human is involved in the production process. In this case, operators are just there to act in case the machine stops and also to double check through random sampling that the automatic control process are continuously effective.

5.3.6 Autonomation and Statistical Process Control

5.3.6.1 Autonomation

Five of the eight manufacturing sites I visited are concerned by autonomation. In these plants, the production lines I focused on were largely automated. The action of the human in the manufacturing process was indeed extremely limited. For example, in one plant mass producing small electrical components, the manufacturing process is absolutely one hundred percent automated: the production line is fed at the beginning by bar coded boxes of components, then robots and conveyors work together to assemble and weld components until the final product to be completed and packed away in boxes ready to

dispatch. In addition to production "value added" operations, the line also includes all the operations of visual, dimensional and functional controls that are automatically performed for one hundred percent of the parts. When a non-conforming part is picked up, it is automatically rejected. If the quantity of rejections is too elevated, the line stops by itself. The role of the operators is definitely not to make the product with their own hands but to react as fast as possible when the line reports a problem or stops. In addition to first level maintenance operations, another of their critical role is to confirm trough process and products audits (countermeasures) that all the automatic control devices of the line are functioning precisely and do not drift.

In another facility producing heat-treated and machined parts, one of the production line is really highly automated. Raw metallic parts are injected at the beginning of the line and finished parts are going out of the process after undergoing a dozens of automatic operations not involving any human touch. Many systematic checking operations, such as dimensional or eddy current controls, are incorporated in the process. Nevertheless, this process is not "autonomation" perfect: many quality controls of the heat treatment (superficial and core hardness, induction depth…) are not performed in real time for one hundred percent of the parts but made in a sampling and destructive manner by an operator. It implies that, in case of problem, a full batch of parts would be affected whereas only one part would be concerned in a process respecting perfectly the autonomation principles.

5.3.6.2 Statistical Process Control

Statistical process control (SPC) is a relatively old Quality technic which goal is to keep under control processes that could have a tendency to drift. The principle of this method is to periodically measure a variable (that could be a dimension, a pressure or a flow for

example) to follow its variation over time and indeed correct the process before this characteristic exceeds the authorized limit. This correction is ordinarily performed automatically (the stroke of a tool can be realigned for example) or even sometimes manually (when a change of tool is required after it is totally worn for instance). Most of the company using autonomation I visited (especially in the mechanic and the micro-electronic industries) heavily insisted in the greatest importance of this non-Lean methodology to ensure satisfying levels of Quality and stability in automated processes.

5.3.7 Autonomous Production Teams and Andon

Even if they do not have the same maturity in terms of Lean deployment, all of the companies I discussed with implemented the Autonomous Production Teams organization in their shop floor. They unanimously explained me that this type of organization is a preliminary compulsory requirement that must be implemented in conjunction with any Lean transformation.

In fact, the concept of Autonomous Production Teams means that the production is organized around a team leader covering a part of the production (a set of machines for automatized lines or several steps of production for manual work). This team leader is usually initially chosen among the operators. He is an operator that has a significant knowledge and experience about the process and knows how to perform all the steps of his responsibility zone (usually four to six). He also knows about the previous steps (its external or internal suppliers) and the following steps (its external or internal customers). He is also recognized by the operators he leads as being very competent in a technical point of view and as an “open-minded” partner by his peers (internal suppliers and customers, support services supervisors).

His roles are to really be the chief of his zone in the same way an entrepreneur is for its business. He is responsible for the Quality of production, for the respect of the production planning, for the efficiency of the production and also for the safety of his colleagues. He is as well in charge of managing the first level of the problem resolution process. But, before anything, his first mission is to be constantly available to help his colleagues (from five to ten most of the time) mainly by immediately answering to any call coming from them (Andon) and by temporarily replacing them for a short period of time if absolutely required.

Andon may have different meanings depending of the type of process. In automatic processes, an Andon alert means that the machine automatically stopped the process as it detected an anomaly in one of the controls performed by itself (process parameter out of a predefined range, control of a product characteristic out of specifications, functional feature of the product not in conformance…). For manual processes, an Andon alert does not systematically imply that the production line need to be stopped: it basically means that an operator has detected an issue and requests the support of his team leader. The team leader will then decide if the alert requires the line to be stopped depending of several criteria such as the criticality of the issue, the time needed to fix it, the difficulty of the potential repairs or the possible impacts on other products.

To make his tasks easier, the team leader has a direct access to the support services members of the Autonomous Production Team who generally are from the process engineering, supply chain and Quality departments and, in many cases, are located in the same room as him.

The team leader has no hierarchic link with the operators he leads and reports to a production supervisor (sometimes called “section manager” or “group leader”).

The production supervisor habitually leads three to five team leaders. He is in charge of the administrative work and of supporting, as a coach, his team leaders for any concern (Problem Solving, andon, escalation…).

The Autonomous Production Team is key in a Quality point of view. Its goal is not only to target not to create any defect trough the operations it performs but also, and before all, not to pass any problem to the next step whoever is responsible for the creation of the problem (previous steps, external suppliers, engineering, maintenance…). It really takes the ownership of the entire product and the whole accountability for it in the Quality standpoint.

If something wrong happens, the Autonomous Production Team is in charge of reacting immediately to circumscribe the problem in order it not to affect its customer and not to stop the production line. It will lead the operations of control of the "in progress" and inventory products and put in place the possibly painful interim corrective actions (ICA) that will allow the production line to run despite everything (sorting, rework…).

For the Problem Solving part following the mitigation part, the Autonomous Production Team will provide the necessary information (symptom, problem description …) and will assign the issue to a specific service. It will also launch the escalation process if the problem is too complex or too long to be solved.

For those two missions, the Autonomous Production Team's role is to be the "corner stone" that will federate the support services around the problem mitigation and solving.

Considering its major role, its members need to be constantly engaged for Quality in order all the Quality system not to go down. All the organizations of the company need to understand and demonstrate trough concrete actions that their first priority is to support

the Autonomous Production Team. According to a large majority of the people I interviewed, this is doubtless the first motivation tool.

For example, in many Lean companies, managers of support services and top managers bring their support through their regular participation to the SIM meetings led at the Autonomous Production Team level.

5.3.8 Short Interval Management and escalation processes

All the participating companies implemented this Lean process. It is nearly identical for the first two levels.

The first level is based on a meeting systematically facilitated by the team leader (or section manager sometimes) at the beginning of each working shift. The meeting brings together the members of the Autonomous Production Team during around five to ten minutes in front of the production team board (recording, among other things, operation information of the previous days). The agenda of the meeting is always the same every day and is usually divided into four main topics: People, Quality, Velocity and Costs. The team leader starts by summarizing for each of this item the results of the previous day compared with the targets and lists the highlights. Then comes the review of the new problems (or improvements opportunities) to address and of the status of the pending problems. Three main types of decisions are taken during this meeting:

1. The team takes immediate reactive actions to unlock a problematic situation or to avoid a situation to become problematic or worse (production line stop, lack of material, lack of people….).
2. The team decides in a consensual way if a problem is real and disserves to be addressed in the Problem Solving process.

3. The team decides if it can solve the problem by itself with its own means or if the problem needs to be escalated to a higher level (because it is too complex, requires the intervention of other services or because it has not been solved during the timeframe initially defined for examples).

For example, one of the companies involved in the study uses a system of T-cards to manage the "life" of the problems or opportunities at the Autonomous Production Team level. Problems from each topic are manually recorded on a T-card after review and validation by the team (consecutively by all the working shifts) and is addressed to one "physical" colleague personally accountable for its resolution. The T-card is placed on a specific board and mainly reviewed in case of time delay, for closing review or at the initiative of the problem owner (request for intermediate approval by the team, additional time request, analysis feedback…).

As a second example, another company is using a white board as problem Management medium. Instead of T-cards, A4 templates are used to record the issues and the necessary updates. The board is split in seven columns. Each of them represents a day. Every day, the A4 sheet is moving from one column to the next one. As soon as the problem is solved, the sheet is removed from the board. If, after seven days, the problem is still pending, it is automatically escalated to the hierarchical manager for action.

To sum up, the level one of the Short Interval Management process is simply the mix of an organized, ritual and systematic meeting, using a board as a recording and visual tool dealing with day to day problems experienced by the production team (quality ones of course but also people, maintenance and safety ones for instances) and where consensual decisions are taken (reactive, Problem Solving and improvement decisions).

The level two SIM meeting usually held a few hours after the first one. It is also facilitated by the team leader (or the section manager) at the same place as previously and gathers the support services members of the Autonomous Production Team (supply chain, maintenance, process engineering…) and potentially (often on specific request) people from other services (engineering, human resources…). All the operators do not participate in this meeting that habitually last around fifteen to thirty minutes. Its purpose is primarily to work on the Problem Solving topic: root cause analysis can be conducted, potential solutions can be discussed, problems can be addressed …

The third level is led by a manager supervising five to ten section managers. It gathers the manager, its production supervisors and other managers from the support services. Evidently, this meeting aims to review the results at an upper level (shop floor, building, full value stream…) in the same way the first levels SIM meetings are. Nonetheless, its first role is to be an escalation forum where all the problems escalated by the production supervisors and their team leaders are discussed and addressed. Depending of the company, it happens every day but most often just one time a week.

The fourth one is similar as the third one but is held at the facility director level and regroups the department directors. It usually takes place one time a month.

In some companies, a fifth level is mentioned. It is relative to the regular one on one meetings managers have with their direct reports. Among other things, this meeting is dealing, in a transverse way, with problems raised in the SIM process. During this meeting, the most important role of the manager is to coach and help his collaborator with his list of issues and associated projects in order him not to be blocked.

Another important feature of the SIM process is that a feedback coming from the upper level (in case of escalation) must be systematically provided at the occasion of each SIM meeting: for the system to work, the upper level must consider itself as being beholden towards the lower ones. If it is not the case, the all system will certainly collapse quickly.

5.3.9 Problem Solving

As previously noticed, the Short Interval Management organization is central in the Problem Solving process in a Lean manufacturing organization. On the surface, the Problem Solving process of Built in Quality does not look significantly different than the one used by any non-Lean ISO 9001 certified traditional company and is very closed to a process companies call QRQC (Quick Response Quality Control). Nonetheless, and as it will be detailed in the next paragraphs, major differences are materialized notably not only through its associated specific organization and systemic coaching process but also thanks to significant details in the methodology, a rigorous manner of prioritization and a systematic process of escalation. With BIQ, Problem Solving has become an organized company priority and is not only the task of "isolated" Quality agents anymore as it could have been the case by the past.

5.3.9.1 Problem Solving organization

Figure 22 synthetically describes the full process of Problem Solving as it is utilized in the Lean most advanced companies I worked with during the applied research phase.

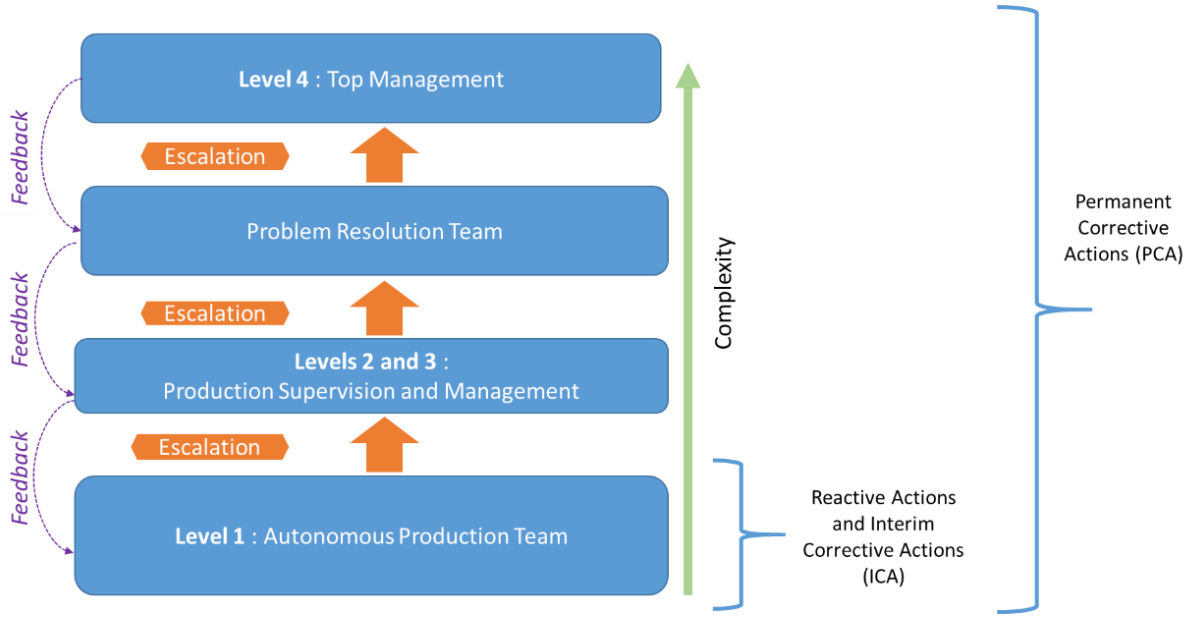

Figure 22: Problem Solving and Short Interval Management organizations

The Problem Solving process is literally built on the skeleton of the SIM process but in these Lean advanced plants, an additional organization (occasionally named “Problem Solving team” or “Advanced Problem Solving team” or sometimes “Smartline”) has been engrafted. As expressed on figure 22, it is located between the Top and the Production Management levels. Most of the time, this organization is driven by a “third party” and transversal manager sometimes reporting to the Quality Manager. It is composed by department managers having access to significant resources, a high and immediate power of decision and reporting to the top Management. The meeting frequency may vary from one week to one month.

The purpose of this organization is to deal with the issues that could not be resolved on time before because of many different reasons such as a too high complexity requiring high skills or a specific transverse project to be launched, an analysis or resolution phase requiring external competencies, a solution demanding a significant funding to be

implemented or simply because no owner has been assigned. During each meeting, only the problematic issues are reviewed in an absolutely systematic manner.

This organization has no technical prerogative: it does not solve the problems by itself and never discuss the technical details. Contrariwise, it firstly tries to understand the reasons why the previous steps failed (system side) to properly solve or address the problem. Then, it aims to unlock the situation by, for example, nominating an owner, asking for complementary preliminary analysis needful before going further or by designating a project leader and allocating the associated resources.

The escalation process coupled to this organization is really effective to avoid the problems judged worthy of going in the Problem Solving process to be temporary or definitely lost.

It is noticeable that in one company systematically having a large amount of problems in the pipe, a similar authority has been added before the escalation to this organization. His role is, mainly at the team leader or supervisor levels to valid that the escalation is really needed, to verify that the pre-analysis contains enough elements, to find an owner, to record the issue as being escalated, to verify the effectiveness of the actions carried out and finally to close the case.

5.3.9.2 Problem Solving methodology

The Lean Problem Solving methodology frame is similar to the traditional ones generally practiced in most of the companies (sometimes called 8D forms). Nevertheless, even if it remains very simple, it insists on some critical steps (see figure 23) and is, most of the time, recorded on an A3 handwritten paper sheet.

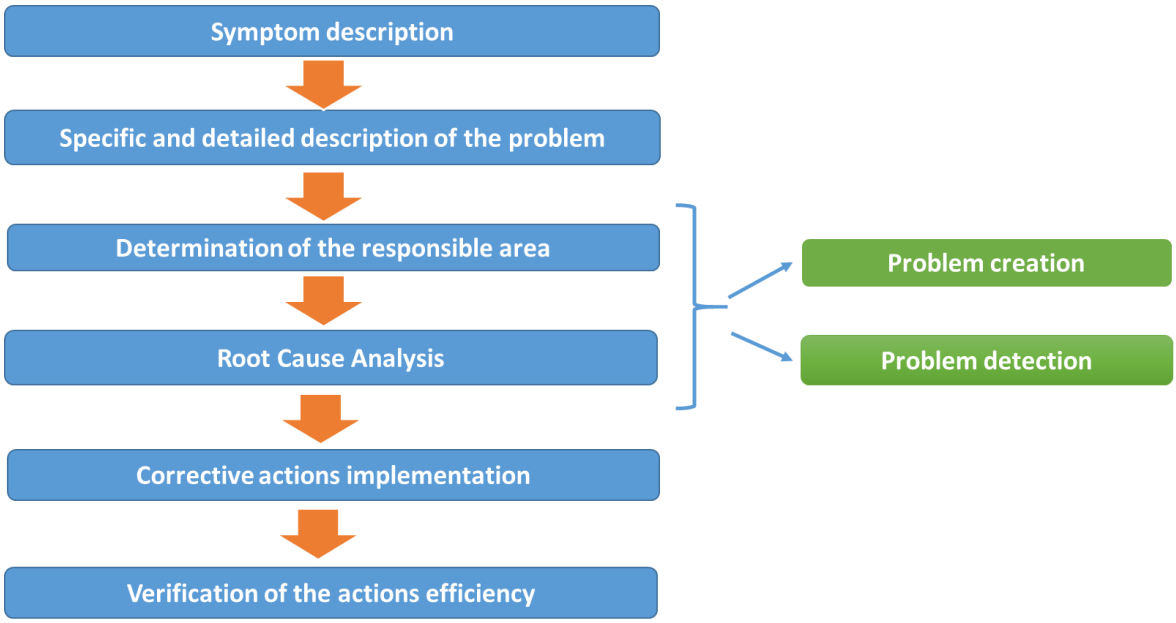

Figure 23 : Problem Solving process schema

5.3.9.2.1 Symptoms and problems

The first step of the Problem Solving process is the symptom description. It is usually considered as the easiest one as, generally, a simple picture is enough to describe the symptom. Most of the time, the symptom is not the problem. This is the manifestation of pain easily detectable. People do often mix symptom and problem. A problem is a drift of a feature directly causing the symptom that can be factually characterized according to a specification or a print. For example, for hydraulic components, a symptom can be an oil leakage and the associated problem can be the fact that a bolt is not well tighten.

The definition of the problem is highly critical for the rest of the Problem Solving process. It must be specific (the failing element must be mentioned) and detailed (the reasons why the element causes a symptom shall factually be described with a reference to a range). A correct description of the problem for the previous oil leakage issue could be: “The bolt

tightening torque was 13 NM as the design specification mentions this characteristic to be between 30 and 35 NM. An oil leakage resulted of this non conformity".

Some companies have really understood that those two first steps are critical for their continuous improvement journey. For example, one of them developed a specific A4 form called "Quality Alert". The first side of the sheet is dedicated to the symptom description and the second side to the problem description. A free space is available for the visual information such as pictures or copy of prints whereas another one is dedicated for the written description in addition to boxes recording specific data mainly linked to traceability such as, for example, date, reference of the part, area of detection, quantity affected, writer name, responsible for the defect (external supplier, engineering Dept., …) …. The purpose of this "Quality Alert" usually filled by the "victim" of the problem (or, more often, by a Quality Agent) is to be clear enough in order the responsible to be able to perfectly understand the issue and, indeed, to be able to react immediately. The time taken to fill this sheet is significant: the Quality Agent needs to understand the issue very well as he needs to collect data, conduct pre-analysis and make measurements where the issue is taking place. Nevertheless, this company is absolutely convinced that the effort worth it considering the increase of efficiency of the responsible in terms of reactivity and accuracy. For internal issues, those two parts are included on an A3 form also including spaces for the other Problem Solving steps.

5.3.9.2.2 Sorting Phase

The next step of the analysis is, of course, to precisely identify where the defect (and eventually by who) was created in order, on one side, to be able to address it for corrective actions but also, on the other side, to discover at which step the defect should have been

detected to understand why the QATS "stop capability" (see previously) failed. Starting by drawing a process flow can significantly facilitate the exercise.

5.3.9.2.3 Root Cause Analysis

Then comes the Root Cause analysis step. The goal is not only to find the superficial cause of the problem but also to go further and find the deep root cause(s). Classical tools like Ishikawa and "5 whys" are usually used for that purpose. This analysis must be performed not only to find out the reasons why the defect has been created but also and overall why the defect has not been detected as close as possible to the defect creation location.

Some facilities go beyond and look for three different kinds of root causes: they focus on the "detection" side (why the problem passed the Quality Gates?), on the "technical" root cause (why the problem has been created?) and on a "system" root cause (what conditions in the system allowed the "technical" root cause to happen).

5.3.9.2.4 Corrective actions implementation

The next step is dealing with the corrective actions. Those actions, derived from the conclusions of the step of root cause analysis, target to be the solutions that will improve the process in order it to definitely never reproduce the same issue. When the root cause analysis is complete, those actions will also aim to preventively avoid other issues potentially having the same root causes to happen.

5.3.9.2.5 Verification of the effectiveness of the actions

This step is a very important part of the process that must not be underestimated. All companies agree that the process of Problem Solving cannot be closed until this phase is achieved in serious way. Usually, companies use a chart where they inscribe day after

day the number of occurrences of the problem to document this phase. The follow up time range depends of the occurrences intensity. If, for example, the quantity of issues per day is significant and constant before the beginning of the solving process, the number of days of follow-up can be limited. It could be longer if the occurrences of the defect are relatively low and irregular in a time standpoint. Habitually, the control period of time during which zero issue needs to be detected is from one week to two months.

5.3.9.3 Coaching

The Problem Solving methodology as described above seems to be very easy. But, in reality, it is not as simple as it looks. People having a low practice of the methodology often make mistakes in one of the phases or does not go deep enough in the root cause analysis step for example. In most of the companies, an initial training dealing with Problem Solving is naturally provided but some companies realized that it is not enough and that a long time "on the spot" coaching is required for teams to become more and more effective with the Problem Solving process. Sometimes, the coach is an experienced engineer totally or partially dedicated to this job. He assists to Problem Solving sessions and reviews with a constructive critical eye the A3 sheets with the Problem Solving leader (that can be anybody). In the most matured companies, the coach is nobody else than the hierarchical superior of the Problem Solving leader. This system requires everyone not only to be involved in the Problem Solving process but also in the continuous learning one.

5.3.9.4 Escalations in the Problem Solving processes

In many companies, the process previously described is not always fully performed at all levels mainly as it requires a significant amount of resources: it takes a long time, necessitates a full team, competencies and experience in Problem Solving. This is the

reason why many companies reserve it to a second level of escalation. The first level usually uses a “simplified” and fastest version of this process.

For example, in one automotive company, the team leader has to choose one problem per week. The description of the problem as well as the identified root causes, the corrective actions and the verification of the effectiveness are reported on an A5 form. The sheet is filled by the Autonomous Production Team through a quick brain storming session. To be fast, no complex Problem Solving tool such as Ishikawa or “5 Whys” is used. The actions must be fast to implement, not require any significant investment and simple enough to be directly implemented by the team. The last part is the most important one: after implementation of the actions, the team continue to record the occurrences of the issue. If the problem does not happen again, the team considers that their actions are effective. If not, they may choose to escalate the problem to a more technical team. After one week, a new problem is chosen and so on and so forth.

Figure 24 shows the type of Problem Solving process used according to the level of escalation (from the simplified Problem Solving process to the launch of a specific project and from the Autonomous Production Team level to the top Management one).

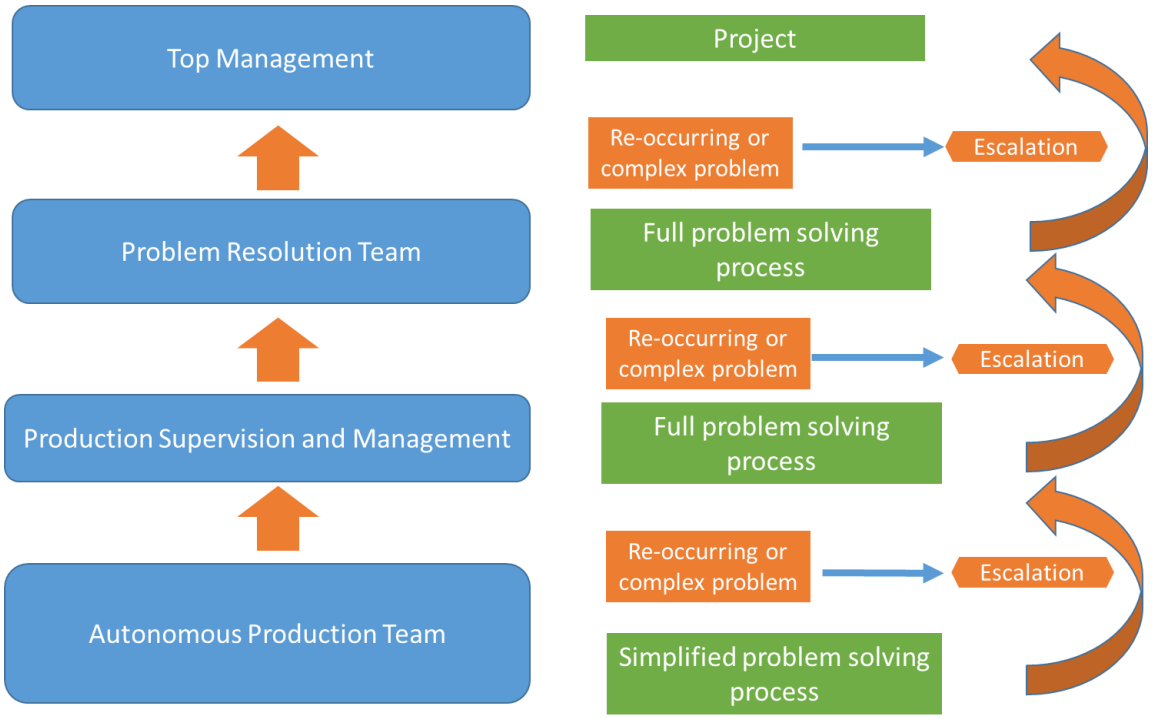

Figure 24 : Choice of problem solving methodology and escalation process

5.3.9.5 Prioritization

At the occasion of each of my visit, I asked an important question (in my view): do absolutely all of the problems have to be injected in the Problem Solving process or not? Sometimes, the answer is yes for companies experiencing a low quantity of problems but, most of the times, it depends of the level of resources available and of the quantity of issues. In this last case, companies defined specific rules of prioritizations.

For instance, one large facility (assembly of machines) participating in the study firstly invented a specific hierarchy to class the issues: problems affecting the functionality of the machines are called majors, problems not affecting the functionality of the machines but that would be visible by the customer are called mediums and non-conformity not affecting the functionality and that the customer would not discover are named minors. In this plant, one hundred percent of the defects have to be corrected (fortunately). All of

the recurring issues (more than two occurrences) and of the major Quality concerns must be treated following the "full Problem Solving process" and a certain percentage of the medium and minor issues needs to be handled according to the "simplified Problem Solving process".

In a few cases I observed during my facility tours, the answer is not completely clear especially when no rule has been written and when all the issues are not systematically recorded in a specific system.

5.3.10 Information, metrics, targets and visual Management

Only the most "Lean matured" companies have a specific and systematic information system that aims to record one hundred percent of, on one hand, the Quality events happening in their facility and, on the other hand, the ones reported by their customers. Those systems usually include, in the first place, a part dedicated to the issue description (Symptom and problem description, area of discovery of the issue, name of the responsible for the creation of the issue, gate that missed the issue, date, shift number, category of the defect…) and the associated reactive actions to immediately circumscribe the problem (including data about the consequences of those actions: scrap costs, rework times, warranty costs…). Then, they also comprise, most of the time, a section dedicated to the Problem Solving made of the analysis, corrective actions implementation and control phases. Finally, they eventually contain a part dealing with the preventive replication of the actions for similar and potential issues to come.

Those systems allow to know everything about what is happening in terms of Quality. With this kind of system, it is possible to completely monitor Quality. For example, facilities are able to edit Quality data at different levels: quantities of issues created per

area, rework time per responsible, defect per unit, average solving times or percentage of problems solved for instance.

Those publications are used in a visual Management view:

1. To enhance the continuous improvement process (as stated in the well-known formula: “only what is measured can be improved”).
2. To make people accountable for the pain they cause and make them feel responsible for solving it.
3. To make possible advanced analysis that could lead to launch “umbrella” projects devoted to improve large fields of problems.

I have been explained by one manager using the analogy of the orienteering race and convinced by the absolute necessity of such a system that, “it is mandatory to precisely know where we are at each moment if we want to be successful. Otherwise, it is simply impossible to find the right path to reach the target as it can only be defined by being the way between a point A (present time situation) and a point B (goal)”.

The most advanced companies of the automotive industries, of the machine construction and of the electrical fields are totally clear about the absolute necessity of that kind of system even if this process requires a significant amount of resources to run well and seems, at first glance, to generate administrative waste (operators and Quality Gates inspectors systematically need to fill the system when an issue occurs, responsible needs to fill their analysis, corrective action and the “victim” must, at the end of the process approve the effectiveness of the actions taken). At the end of the day, it brings a lot more value than it costs.

Nevertheless, some companies I visited are not using that kind of system at all. Some of them even clearly expressed me that they do not feel they need considering their evaluation of the potential ratio "cost versus income" of such a system. Even if they have a more or less clear idea of their situation in terms of Quality, they are partially blind as they often are not able to provide a farseeing and detailed picture: they are sometimes not even able to answer to simple questions such as: are Quality issues a problem for you? How many Quality issues do you face per year? What are your three major Quality problems? What is the "worst" part of your process or product for Quality? Who is responsible for the most of your problems? What is your cost of non-Quality and how is it allocated? …

To be effective and drive a sound movement of accountability and continuous improvement, those records must be supported by an effective system of transmission of the information and, more particularly, of visual Management. Information shall be dispatch in an appropriate way to all levels of the company: they must systematically be displayed and discussed at all the SIM meetings starting from the one of the Autonomous Production Team happening every working shift to the facility steering committee one potentially happening one time a month.

In some facilities, those data split by area (and compared to the year to date targets) are also provided (often by E-mail) weekly or/and monthly to all the stakeholders at all hierarchical layers accompanied by a high level analysis usually prepared by the owner of the BIQ process. In this case, everybody has the possibility to loosely see the results of the others. The recipients are afterward free to go further and deeply in terms of analysis in their respective areas of responsibility to be able to provide detailed

explanations and mostly an appropriate action plan during the next SIM meeting of their level.

According to the managers of those Lean matured facilities, this is the addition of this resourceful systematic issues recording process, the associated analysis process, the regular seamless broadcast of those two last ones across the organization and, finally, the associated visual Management that definitely makes the difference between just looking for a bit of improvement and seeking operational excellence.

A strong clue to evaluate if a BIQ system is effective or not is to make the relation between the capacity metrics and the results metrics. If the capacity metrics are green and the results ones are not continuously improving or are stagnating, it means that something is going wrong in the system and that deeper investigations must imperatively be conducted.

Talking about the way to set the right levels to operational targets, a Quality Manager confided me that, to make outstanding and fast improvements, one of the methods, that could seem at first sight completely senseless, is to set a very limited amount of extremely ambitious goals nearly impossible to reach. Actually, it works because, with a low level requirement of progress (5% to 10% for example), managers will probably be able to just reach the targets benefiting from the "natural" day to day continuous improvements. If the requirement is particularly demanding (50% or 80% for instance), managers will need to deeply focus on this target that will not be possible to reach without fundamental and disruptive changes in their current processes.

5.3.11 Continuous learning process

A high focus for training and continuous learning is one of the most noticeable characteristic of the Lean advanced companies. They consider people knowledge and

ability to master their processes as being probably the most important asset of their company to enhance the obtainment of high operational performances.

For example, a manager of an automotive company explained me that the initial training and the continuous learning of the operators was critical when I asked him what was, in his opinion, the most important point to make BIQ successful. He told me, as well, that each operator newly hired in his company has to follow a cursus of seven days of specific training before starting to work in the production line. He also mentioned that before being completely autonomous at his workstation, each operator is coached by an experienced tutor during a period of one month. During this time, the operator is continuously evaluated not only for his abilities to perform the tasks described in his standard work in the right time and with an appropriate level of Quality but also for his capacities to learn from his mistakes and to work in team. I observed a very similar way of thinking and acting toward training in almost four other Lean matured companies.

In a Lean point of view, learning is not only about initial training and about tutoring. It is, before all, a continuous process dedicated to make collaborators more skilled in their work specialties and, ultimately, to avoid them making the same mistake more than a single time. This learning process is also flexible enough to integrate the multiples changes continuously happening in companies (standard work modifications particularly).

5.3.12 Engagement and culture

5.3.12.1 Burning Platform

Many of the managers I met related me that the implementation of BIQ demands a lot of energy and motivation to be successful and sustainable. The main reason for this is that BIQ requires many rituals (Quality records, metrics updates, daily meetings, problem-

solving analysis….) to be carried out with a sort of “military discipline” at every hierarchical level of the company.

That is why all the employees absolutely need to be convinced that this extra energy is required to reach a next step, especially when the Built in Quality automatisms are not yet ingrained in the company culture.

The business term “Burning Platform”, emphasizing a radical and immediate change due to serious and urgent circumstances, is the appropriate expression to design what the top Management must work on and cascade prior to start this Built in Quality (or even Lean) cultural transformation.

Collaborators (including all levels of Management and especially the first Management row) need an extremely good and strong enough reason to overcome all their natural resistances for the transformation to be successful. If there were no sufficient reason to change, why would the organization change?

According to the conversations I had all along the research work, Figure 25 shows an example of how could be the process of bringing out a Burning Platform that could lead to start the implementation of BIQ.

Figure 25 : Quality "Burning Platform" example

Nevertheless, I have been surprised that one of the companies I visited was not in a hurry with the implementation of the Quality part of Lean. The manager in charge of Lean confided me that Lean deployment was not the priority of his company. At that time and for a couple of years, the focus of the company was to manage an international two digits growth and, thus, answer to the most important need of its customers. According to this company, additional profit that could have been brought by Lean Manufacturing full implementation would have only been a "nice to have" as its profit was satisfying. Its external quality level was also sufficient in its opinion and did not require a radical change of their organization (BIQ). For this reason and as the "Burning Platform" was not strong enough, this company decided to, slowly, launch the implementation of Lean Manufacturing starting by the processes of the supply chain side.

Another manager, in charge of facilitating the deployment of Lean in the European plants of a multinational company, explained me that it was not so easy for him to go ahead in his mission because of the motivation of the local plant Managing Directors. Actually,

the values of the operational targets set by the corporate Management were not challenging enough for the Directors to necessitate a radical change in their manufacturing organization. Moreover, the corporation was not pushing the facilities to implement Lean according to a specific calendar. It was up to the local managing Directors to set the deployment timeframe according to their needs.

5.3.12.2 Management behavior

For Built in Quality to work effectively, the company culture must be Quality oriented. All the actors of the company (from the operator to the Managing Director) must be intimately convinced that Quality is the priority (just after Safety of course) of the company far away before considerations of velocity and costs and that absolutely no compromise can be beard while dealing with Quality concerns. Management must necessarily always behave in an exemplary way in words and deeds. If Management do not behave systematically in this manner, their subordinates will act in the same way and the BIQ system will inexorably and definitely fail.

According to all the Manager I met (without any exception), this uncompromising behavior will strongly contribute to build the BIQ culture required for the whole success of Lean.

For instance, a Lean Manager I met told me that a change of Managing Director is a key moment for the sustainability of a Quality policy especially in the Lean standpoint. He explained me that the Management in place in the facility needs to really make sure that the new Director clearly understand what to be a Lean Facility implies. He needs to understand that point not only in terms of performance but also in terms of organization and culture in order to avoid him to take decisions that would lead to the destruction of the efficient Management System that has been built sometimes in about a full decade.

In many companies I visited, Managers (from all levels and departments) demonstrate their engagement through their regular and active participation in shop floor events such as levels one and two Short Interval Management meetings or to improvement projects led at this level (sometimes called Kaizen or Rapid Improvement Workshops).

In some other ones, Top management (even the Managing Directors) frequently participates to the highest level of the Problem Solving process or requests the main operational problems experienced during a certain period of time to be briefly presented (from the symptom description to the actions proposed) to them during a weekly half an hour session.

5.3.12.3 Quality culture enhancement

To reinforce employees pride and engagement towards Quality, companies are usually using a set of several tools:

1. A Quality Management System (such as ISO 9001) already implemented for several years is, of course, a precious preliminary asset for the Quality culture to be robust as, for instance, people are already used to some Quality routines, behaviors and way of thinking.
2. Individual and Team Quality targets aligned with high levels company ones are now largely deployed. Those targets are reviewed regularly and closely linked to the yearly performance evaluation review itself aligned with potential salary increases.
3. Internal challenges between teams are sometimes also utilized to enhance the pride of teams about Quality. For example, in one company I visited, Quality results (found and missed defect per machine) were used to positively discriminate the teams of one assembly line. At the beginning of the competition,

each of the teams had the same machine made of an identical number of parts. Each time the team weekly results were under the target, the machine of the team was amputated of one part. Each time the results were at the targeted level, one previously lost part was regained. Every week, a ranking was established and after a certain period, the Managing Director of the plant awarded prizes during a dedicated ceremony.

4. Visits to customers or dealers are also organized by a few firms to consolidate the Quality culture. This initiative works most of the time very well as the selected employees, whatever their level in the hierarchy, are confronted to the customer of the product they personally contributed to manufacture. Sometimes the customer is happy, and this strengthen the feeling of pride of the collaborators towards the level of Quality his facility is providing and, occasionally, the customer is unsatisfied: the employees come back reinforced with the feeling that additional efforts must be done in terms of Quality to delight the customer.
5. The system of Quality Gates and the associated immediate feedback is also a very good means that reinforces the Quality culture. Each time an operator is doing a mistake, the Quality Gate inspector is not reacting with the idea of blaming him but rather with the intention of helping him to make progresses and systematically remind him that Quality is not an option.
6. Another very simple but highly efficient way to consolidate the Quality culture is to avoid to forget to congratulate and thanks people time to time when they are making their job well or providing any kind of improvement ideas. Respect is an essential behavior for Lean success to come.

Even if all the concepts constituting Built in Quality seem to be very simple to understand and to apply, BIQ culture often takes several years to integrate fully the existing culture of the company. The main reason is that Lean in general and BIQ in particular are not "natural" to apply. BIQ requires a significant and constant effort to be effective, cannot properly be partially used or once in a while.

According to the most mature companies I worked with, here are some typical reasons why BIQ implementation fails or takes time to bring significant results:

1. The required resources have not been provided or adequately deployed (Quality gates understaffed, Poka Yoke not deployed enough, Man-Machine independency not enough implemented for financial reasons).
2. The regular rituals prescribed by Lean Management (SIM meetings, Quality records, Problem Solving process….) are not systematically applied.
3. Top Management does not behave in an exemplary way or does not demonstrate clearly its commitment to the BIQ principles.
4. Visual Management and the associated metrics are not widely dispatched enough or not freely available to everybody in the organization.
5. Quality targets are not pertinently chosen or not effectively cascaded from the Director level to the operator's level.

5.3.13 Process risk analysis

In several large companies having complex processes (Mechanical, electric and microelectronic fields particularly) Process Risk Analysis is often associated with Built in Quality. This process occurs upstream (see figure 19) as its main purpose is a preventive one. Those companies have understood that changes within their organization

or in their processes (change of production processes, of products, of people, of suppliers….), whether simple (modification of a line in the standard work for example) or major (new product or new production line for instance) are the main source of degradation of their overall performances. Actually, uncontrolled changes may potentially bring new wastes (stocks, efficiency problems, Quality issues, supply chain slow down…) if their integration in the existing value chain (from the design to the ramp-up phases) is not sufficiently mastered.

Companies usually use tools such as Failure Mode and Effects Analysis (FMEA) or Business Risk Management (BRM) to deal with that kind of problematics. Their purposes are primarily to properly and efficiently manage the changes by anticipating, limiting and, at last, mitigating the potential troubles.

Some companies (four of the largest of this study) even use a system which purpose is to manage the validation of the implementation of the change. Those kinds of systems work like a classical database: employees submitting a change record their proposal in the system. Since then, the request is going through a set of people that must approve the change before its implementation starts. The requester shall preliminarily include all the details and documents needed for the sort of change he asks for. The main goals of these approval systems are to make sure all changes are valuable, “under control” and, finally, that all the stakeholders (from the top Management to the first line Management of all potentially interested services) are informed, contribute to the decision and are appropriately involved in the potential future implementation of the change.

5.3.14 Built in Quality implementation sequence

According to some Managers I interviewed, BIQ implementation shall preferentially follow a certain logical sequence. Here is a synthetic list of the most important points describing this sequence:

1. Establish the BIQ Policy first.
2. Assign visible BIQ targets to all stakeholders.
3. State clearly the production sequences (flow chart).
4. Define the Quality Gates physical location according to the process flow chart.
5. Create the Quality Gates checklists and the associated maintenance organization.
6. Physically implant the Quality Gates.
7. Define and deploy the problem solving processes and organization.
8. Implement the communications, feedback loops and escalation processes.
9. Deploy the process monitoring organization.

5.4 Integration with other Quality Systems

5.4.1 Integration with Kaizen and Six Sigma

Kaizen and Six Sigma methodologies play a major role in the Problem Solving process. As previously discussed, if the problem is too complex, it is escalated to a higher level of hierarchy. In this case, a project facilitated by a dedicated project leader needs to be open. In two of the companies I worked with in this study, Six Sigma methodology is very well implanted in the culture. It means that if a project needs to be open for Problem Solving reasons, this will be under the Six Sigma form. Those companies do not only consider the Six Sigma methodology as being a statistical set of tools, a common language and a type of organization but, before all, they understand Six Sigma as being a methodology to

drive a project in a strictly organized way that will maximize the chances of success. Six Sigma and particularly, in this case, the DMAIC approach are used as a complement of the Lean Management System in the sense they only focus on complex one shot problematics. The DMAIC approach structures the project involving the team, the stakeholders and sponsors through the gates meetings placed after each of the five phases of the projects (Define, Measure, Analyze, Improve and Control). The Six Sigma project can be led by a high skilled Black Belt Project Manager and last several months if its complexity level requires it or by a Green Belt Project Leader partially dedicated to projects during a few days if the project complexity is low enough.

In the other companies not using Six Sigma, projects are however launched in a similar way. Nevertheless, instead of using the Six Sigma strictly defined methodology, a "homemade" Kaizen approach usually based on the PDCA methodology is utilized. In this case, instead of following the five phases of the DMAIC methodology, the Problem Solving project will go through the four steps of the PDCA wheel (Plan, Do, Check, Act) initially proposed by Deming and highly promoted by the ISO 9001 Quality Management System (see paragraphs 4.3.5 and 4.3.6).

5.4.2 ISO 9001

All the companies participating in this applied research are ISO 9001 (2008 revision) certified for a long time. When I discussed with people about ISO, I have been told several times that the purpose of the ISO certification process was not to help them to implement a Quality Management System that would be the key to satisfy their customer. In fact, most of them confessed me that they were ISO 9001 certified only because certification has become a compulsory and prerequisite process requested by customers and the market in general. If you are not ISO 9001 certified, you will not be allowed to make any

business! Sometimes, the knowledge of my interlocutors about ISO 9001 and the way it was running in their company was amazingly poor! Some of them admitted: “Honestly, none of us does really focus on ISO 9001 stuff; it is only the competence of the certification service”!

Nonetheless, when I dug a little bit, I have each time been pleased to discover that, actually, almost all of these companies had in place a strong and pretty clear Quality Management System very well known by the different actors. People sometimes do not really know the names but know what the organizations, the processes, the procedures are and how the fundamental principles carried by ISO are practically deployed in their company: Customer focus, Leadership, Engagement of people, Process approach, Improvement, Evidence-based decision making and Relationship Management.

In reality, as in those companies ISO 9001 is in place for more than twenty years now, its concepts have literally been absorbed by the Management System in use in a day-to-day basis. This one is going, most of the time, far beyond ISO requirements. That is the reason why many employees do not realize anymore in a conscious way that ISO 9001 is a primary factor of success. It explains as well what the job of people working in the service dealing with certification (sometimes called “the guardians of the temple”) is: to make changes in the company Management System remain in line with ISO 9001 prescriptions and not anymore the opposite as it could have been maybe ten or fifteen years’ sooner.

When I asked him about ISO 9001 audits, a manager of a car production plant told me: “You know, when auditors come to our plant, they are not looking anymore for what is missing for our system to be ISO compliant or what managing process is failing. They

are actually searching what could be the future concepts ISO could potentially add in the next revision of their 9001 standard".

In another company, a Quality Manager explained me: "In my opinion, ISO 9001 incorporates the fundamental concepts required for a Quality Management System to start being effective but, in fact, it is absolutely not sufficient for us and we need to go widely further to remain competitive by adding, for example, Lean or Six Sigma features to our Management System. Ultimately, ISO is an outdated standard as it only includes concepts that were at the forefront of progress ten or fifteen years ago".

To summarize, ISO 9001 is, for the Lean companies, a very strong basement which fundamental principles are culturally perfectly digested and that can be very well integrated in a more advanced Management System.

Nevertheless, it must be granted that, in many companies, the documentation of the Management System could be simplified or, at least much more centralized. For example, more than one company possess one standard for their own Quality Management System, in addition with a "homemade" Lean Management System one and still continue to independently use ISO 9001 standard.

5.4.3 Synthesis

Figure 26 introduces a picture of how Built in Quality, Six Sigma / Kaizen and ISO 9001 can ideally be integrated to seek Operational Excellence using the symbolism Pepper et al. proposed (see paragraph 2.6.3).

ISO 9001 Quality Management System "offers" the fundamentals principles and the basics notions that seek to be integrated in the company Quality Culture. Built-in Quality is the additional Management System that not only details ISO 9001 but also allows

continuous progresses to happen while bringing rigorous and, most of the time, "down to earth" processes. Finally, Six Sigma / Kaizen bring organized methodologies to overcome complex problematics in a disruptive manner.

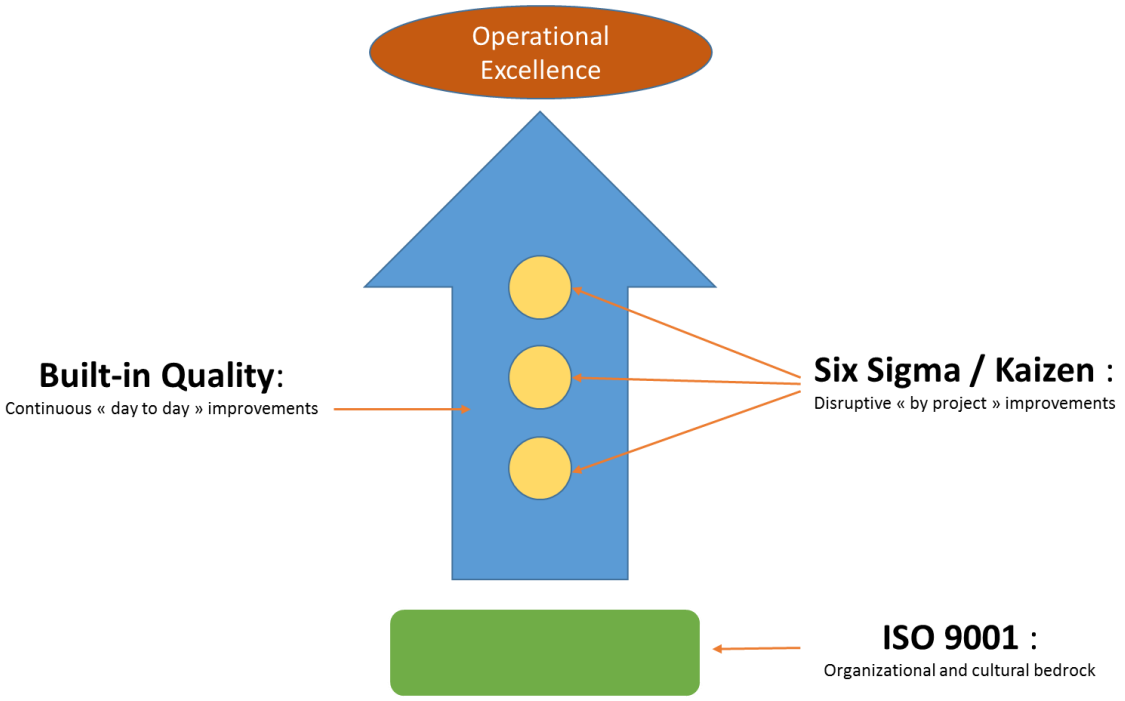

Figure 26: Schema of the typical integration of the different Quality systems in a "Lean manufacturing company"

5.5 Just in time and Built in Quality synergies

Looking at the Lean House, BIQ is one of the pillar as well as Just in Time. To sum up, Just-in-Time gathers the lean concepts, processes and tools dealing with the velocity part of businesses (one-piece flow, pull, Kanban, captive production lines, U shape production lines….).

According to many of the Managers I met and as the literature states, the link between those two pillars is tight:

1. Quality is a prerequisite for Just in Time to work well mainly because a one-piece flow captive production line will not survive if it undergoes a continuous flow of Quality events disturbing its progress. For example, a line of ten steps working in

a eight hours shift and theoretically able to produce sixteen products encountering one event per step per day stopping the line during fifteen minutes will only be able to produce eight products instead of sixteen. This represents a considerable loss of productivity of fifty percent!

2. Just in Time will boost Built in Quality processes. This is the corollary of the previous example: as the consequences of Quality events will not be hidden anymore by the inefficiencies of the production line (buffer stocks for example…), it will become mandatory to work effectively on the definitive resolution of the problems in order them not to happen again and disturb a second time the line.

For instance, I visited a company that just proceeded to the Lean transformation of one of its assembly production lines.

Previously, the assembly line was non-captive, made of a certain number of independent steps of several hours and operated by two or three workers. When a step was completed, the in process product was moved to the next step (or, at least, to the buffer zone located just before this operation). At that time, they already started to implement the processes of Built in Quality (Quality Gates, feedback loop, Problem Solving processes…). It brought significant improvements in terms of Quality but reached a step after a few years. According to them, the main reason for this step was the difficulty to make people and especially the first line of production managers understand that it was important to highlight and then solve the problems so that they would work more serenely. This task was uneasy because, in fact, people were not so disturbed by Quality defects because of the design of the production line. Their work was “protected” by the buffers of located everywhere along the line. In case of problem, they used to put the issue aside and

continue to work with another product leaving the “privilege” to others to deal with the problems.

To prepare the transformation (around twelve months before the ramp-up of the new line) and avoid a disaster to happen, they decided to launch a specific action plan to reduce the risks linked to the “as is” situation. On the Quality side, they worked on preventively reducing risks mainly thanks to advanced and increased technical investigations the quantity of issues happening on the lines below a certain threshold and mainly generated by external suppliers, by product design anomalies and by the production lines themselves. They also conducted Failure mode and Effect Analysis considering the specificities of the new line and the new way to produce the machines to anticipate a maximum of potential problems. In conjunction to this technical work, they launched a specific communication campaign dedicated to make all those stakeholders understand that the consequences of this issues they would create will have a dramatic impact on the new Lean designed production line.

After the transformation, the production line was continuous (driven by a conveyor), totally captive (defective machines could not be removed from the line anymore before the end of the line) and respected the one-piece flow concept (the machines in progress were not processed by “batch” and no intermediate superfluous buffer stock was created). Even if the preventive measures taken by the transformation team were effective, the ramp up of the new line was not so smooth and the first time have been really tough. Nevertheless, the Built in Quality processes were in place from the beginning and quickly brought amazing improvements. During the first weeks, they encountered a dramatically increase of the issues detected. After around two months, the trend reversed and, after

about a six-month period, they experienced unexpected results significantly better than the ones they had at the end of life of the mature previous line.

5.6 Lean extended definition of Quality and associated consequences

For the companies the most experienced in the application of Lean Manufacturing, the understanding of Quality goes far beyond the simple application to the product. Obviously, product Quality remains the core of their concerns. Nevertheless, they understood, in a second time, that the Built in Quality Management System could also be applied in a much broader context of continuous improvement as the value chain cannot be reduced to the sole manufacturing part. Indeed, it could include all the activities from the quotation to the after sales service (such as procurement, product and process engineering, maintenance to name the most common).

As BIQ demonstrated after generally two to five years its ability to bring outstanding results in the manufacturing field, many advanced companies (almost five of the ones I met) started to deploy its concepts in other fields. They usually start in related services such as Maintenance, Process Engineering, and Quality. Then come services farther from the production activities such as Product Engineering, Information Services…

Even if there are sometimes some resistances, those services easily understand globally very well what the company is waiting for them in terms of BIQ implementation as the large majority of them have already been involved in the manufacturing BIQ process.

The definition of Non Quality is not anymore limited to the product but to all activities having an impact on the value chain in the cost or velocity point of views. Non-Quality can therefore be defined as being everything that can disturb or decrease the optimal effectiveness of the complete value chain.

6 Limitations

As explained in chapter 3.5, the applied research part of this study has willingly been limited in scope to manufacturing companies. Any extrapolation of its results to non-manufacturing cases may therefore not be valid.

Moreover, even if this study is based on a relatively large sampling of a dozens of companies from various manufacturing domains, it is important for the reader to remember that, as this applied research work is based on case studies, the conclusions and recommendations of this paper may not be effective for a generalization to every kind of companies.

Indeed, the qualitative and exploratory natures of this research (based on interviews and observations from plants visits) contribute to give a partial and subjective aspect to this study.

Another limitation of this work also comes from the limited scope of the sampling: even if the companies involved were diverse in terms of nationalities, sizes, activity sectors and backgrounds, all of the plants visited were located in France and the totality of the people interviewed, even if they were numerous, were French. Therefore, the author has naturally not been able to plenty exploit the cultural variable.

7 Conclusions and recommendations

Literature and manufacturing companies are globally aligned on many important points about the Quality part of Lean and, logically, do agree on the most important one: “Built in Quality”, when properly, consistently and rigorously applied, brings outstanding and sustainable operational outcomes as evidenced by the two following examples.

One of the company (mechanical industry) I worked with confessed me that BIQ allowed them to make the following progresses in a two years’ period: 50% decrease of the issues detected all along the production line, 80% drop of the defects detected at the final pre-delivery audit, 50% reduction of the rework times, 60% decrease of the warranty costs (operational causes). Another one (microelectronic industry) mentioned similar results in a four years’ period: 95% drop of the customer claims and 60% reduction of scraps.

Even if the applied research part of this work has willingly been limited to ISO 9001 certified manufacturing companies and French facilities, the dozens of participating companies exhibit a significant diversity (local or multinational, “best in class” or “new comers” in Lean manufacturing, coming from various industry sectors…) that gives credibility and legitimates the findings of this study.

Mainly based on field observations and interviews, this paper gathers and synthetizes a significant amount of knowledge and experience amassed by the participating companies during the last years or decades. The result of this work is reflected through the construction of an original model (see figure 19) detailing the structure of the global Quality Management System of a typical mature Lean Manufacturing facility. In a few words, this one is composed by a “Built in Quality” core surrounded by additional Lean,

Six Sigma and Quality processes and supported by a ISO 9001 Quality System type bedrock.

This qualitative exploratory research modestly contributes to fill the gap with the current literature knowledge as it practically goes further by proposing a holistic and applicable view of the Quality Management System used by Lean manufacturing companies supplemented by many real examples and best practices.

As a next step, future researches could be focused, in my opinion, on the three following topics:

1. on applying this model, in a validation purpose, to non-Lean manufacturing companies.
2. on digging the subject deeper and intensively by, for instance, spending more time in observing a very limited amount of Lean “best in class” companies.
3. on pursuing this research with Lean companies located in other countries than France and thus exploring the cultural side of the subject.

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Annex: Guidance questionnaire for interviews

General company information

Can you present your company? Turnover, employees number, geographic locations, type of products, site organization, customers, suppliers, competitors, creation date, current challenges, type of supply chain (WTO, ATO ...) ....

Initial deployment of Lean

Why did you decide to deploy Lean, when? What was the "burning platform"?

Which “model” did you choose to deploy Lean? (Liker? ....)

How did you deploy Lean? With the help of internal consultants? External ones?

When did you start? What was the process of deployment? (Pilot facilities, step by step?).

Did you work on prerequisites before starting the deployment? (Quality, supply chain ...)

Did you start the deployment of Lean by physical transformations? (New production lines, existing lines upgrades...).

How many time did you need to deploy the entire system? Did that pay off quickly? After how many time?

Are you satisfied with the benefits of Lean?

Definition of Lean

How would you define Lean?

Lean organization

Do you have a specific Lean organization? Management, projects, ...

Do you have a “standard” that describes how Lean works in your company? A training system?

Do you have procedures describing the use of Lean tools (Kanban, Kaizen events, 5S ....)?

Is the concept of Lean described in your current quality policy?

Do you use Hoshin Kanri or "balance scorecard" methodologies to deploy the company's strategy?

Do you use Lean indicators (lead time, OEE, First-Pass Yield, COPQ, Inventory turns ....)?

Has the staff been trained in Lean? From the Director to the operator?

How is Lean organized? Is there a steering committee? Who are its members?

Quality

Who is responsible for product quality? (Production directly ...)

Is the quality a true priority? (Before velocity?)

Could you describe the quality organization? (organizational chart…)

Does the Quality organization pilot the “Built in quality" and problem solving processes?

Quality part of Lean

How would you define the Quality part of Lean? (If appropriate)

Role of Management

How is the management involved in Lean in a day to day standpoint? (Shop floor tours, participation in projects, in weekly meetings....).

Is the management involved in the problem solving process?

Does a steering dashboard exist at management levels?

Visual Management and Indicators

Is a Visual Management system in place (at teams, managers and direction levels)?

How are the indicators structured? (PQVC?)

When are the operational results reviewed? Are problems addressed? Is the efficiency of the resolution process also reviewed?

What is happening if an indicator turns to red?

Do you have performance indicators? Capability ones?

How indicators are deployed? Is there a deployment of the company strategy towards the individual goals? (Strategic alignment). Are salary increases directly linked to performance? Are the objectives individual? collective (by team at the plant level)?

What are the quality metrics you follow? (Customer Quality, scrap, rework, downtime due to quality problems ...)

Is there a reporting system that targets the responsible of the "operational pain" by sectors (Suppliers, engineering, manufacturing, ...)?

How are your operational results evolving since the implementation of Lean? On the quality side in particular?

Lean performance

How is the Lean performance of each sector evaluated? Through actions, results metrics, ...? Through specific audits including a specific grading?

How do you identify the gaps in your system?

At the autonomous production unit

Have you implemented autonomous multidisciplinary teams?

If so, how are they structured? Who is the leader? Who are the members?

What is their role in the management of quality problems?

Do they have the responsibility to circumscribe the problem? ICA management? PCA Monitoring?

Is the quality topic systematically discussed during shift meetings?

How do they manage problem solving? Through specific meetings happening on the shop floor? Actions allocation? Time frame?

How does the visual-management work with regard to quality issues and their resolution?

Is the same approach applied to all problems that may decrease the efficiency of the production line (other than quality)? Supply, maintenance, staff ...

Is an andon system used?

Is this system extended to other types of issues (supply, maintenance ...)? If not, are there any other processes for these ones?

Are the team-leaders and operators trained in Lean? Only in the Lean tools they use?

Are operators directly involved in the problem-solving process?

Who leads the problem solving sessions? Team leaders, supervisors, operators, someone else?

Detection of problems

How are non-conformities detected in production? (Automatic detection, through audits, thanks to 100% quality-gates on certain characteristics? ...)

How are customer complaints handled? How are they recorded? Are production people informed of these problems (display ...)?

Is there a system in place to immediately inform people when a problem is detected? To control the stock and avoid the issue happening again (feedback loop).

Does Management (managers, direction ...) know the most important issues?

Does each section know the most important issues?

Problems solving

Is there a problem allocation system?

Is there a problem solving process (procedure)? How does it work? Are there several levels of resolution?

Is there a hierarchical escalation system if the problem cannot be solved easily? A functional escalation system ("smartline" type)?

Do you use a specific standard form for problem solving (8D, ...)?

Standard Works

Do you have standard works? In production? For support services? For quality control (Quality Gates)?

Is the standard work important?

Who is behind the standard works changes? (Production? ... Methods).

Kaizen

How does your continuous improvement system work?

Do you use a system of cards? Which is at the initiative of cards? Who processes them? When?

Safety

Is safety integrated into the Lean management? (Same type of recording system and problem resolution?)

How is management involved in the safety improvement process?

Extension of the concept of problem

What do you consider to be a quality problem? When the product is not good? By extension, when is the production line stopped? missing parts, maintenance shutdown, lack of staff ...?

In this case, do you have recording and resolution of problems processes that are similar to what is done for quality?

learning company concept

Do you think Lean leads to a continuous learning that is a key success factor?

Lean / ISO 9001 / Six Sigma synergy in the organization

Are you ISO 9001 certified? For what reasons? Since when? What does it mean for you?

Do you have a Six Sigma organization? For what reasons? Since when? What does it mean for you?

Are these systems integrated with the quality part of Lean? If so, how is it materialized? (Procedure, chart ....)?

Table of illustrations