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The Current Paradigms and Methodologies of Continuous Improvement

Commandments for Successful Implementation

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Resumo

O objectivo deste estudo é apresentar uma visão completa da *melhoria contínua*, que justifique a sua importância suprema para as organizações da actualidade. É defendida a ideia de que as organizações devem esforçar-se para melhorar continuamente e explicado o porquê.

Ao analisar a história e a evolução da qualidade e da melhoria contínua em específico, torna-se mais claro como o conceito se desenvolveu e como se vieram a criar os paradigmas e as metodologias mais populares dos dias de hoje. Épocas de crise económica desencadearam revoluções neste campo e muitas foram as organizações que recuperaram e ascenderam ao topo graças aos seus esforços de melhoria contínua.

Estes paradigmas e metodologias - nomeadamente, Lean, Seis Sigma, Teoria das Restrições e Lean Seis Sigma - são dissecados em seguida, a fim de entender em que consistem, quais os seus métodos e ferramentas, e quais os seus pontos fortes e fracos. Através da comparação das primeiras três metodologias mencionadas, é demonstrado que nenhuma delas pode ser classificada como sendo a melhor. Todas são eficazes, mas cabe a cada organização descobrir qual a que melhor se adequa à sua estratégia e necessidades.

O Lean Seis Sigma, por outro lado, integra duas metodologias e, portanto, tem potencial para proporcionar maiores benefícios às organizações, embora ainda tenha de se desenvolver no sentido de criar um modelo de integração eficaz. De modo semelhante, outras metodologias híbridas dão sinais de potencial e por isso se acredita que sejam o futuro da melhoria contínua.

Um objectivo secundário deste trabalho é a identificação de princípios universais que sejam comuns a todos os paradigmas e metodologias de melhoria contínua. Tratam-se de regras ou "mandamentos" que permanecem verdadeiros para qualquer organização e que devem ser seguidos para que as iniciativas de melhoria contínua sejam bem sucedidas.

Palavras-chave

Melhoria Contínua, Qualidade, Lean, Seis Sigma, Teoria das Restrições, Lean Seis Sigma

Abstract

The purpose of this study is to present a complete overview of *continuous improvement*, which justifies its supreme importance to present-day organizations. A case is made why organizations should strive to improve continuously.

By analyzing the history and evolution of quality and continuous improvement in specific, it becomes clearer how its concept developed and how today's most popular paradigms and methodologies came to be. Times of economic crisis triggered revolutions in this field and many organizations recovered and rose to the top thanks to their continuous improvement efforts.

These paradigms and methodologies — namely Lean, Six Sigma, Theory of Constraints and Lean Six Sigma — are then dissected in order to understand what they consist of, their methods and tools, and their strengths and weaknesses. Through the comparison of the first three methodologies mentioned above, it is shown that neither can be classified as the best. All are effective, but it is up to the organization to find which better suits its strategy and needs.

Lean Six Sigma, on the other hand, integrates two methodologies and thus has the potential to provide greater benefits for organizations, although it must still develop further toward an effective integration model. In similar fashion, other hybrid methodologies show signs of potential and therefore are believed to be the future of continuous improvement.

A secondary purpose of this dissertation is to identify universal principles common to all continuous improvement paradigms and methodologies. These are rules or "commandments" that hold true for every organization and must be followed if a continuous improvement initiative is to be successful.

Keywords

Continuous Improvement, Quality, Lean, Six Sigma, Theory of Constraints, Lean Six Sigma

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List of Acronyms

ASQ - American Society for Quality

CFF - Critical Failure Factor(s)

CI - Continuous Improvement

CIM - Computer Integrated Manufacturing

CPQ - Costs of Poor Quality

CQI - Chartered Quality Institute

CSF - Critical Success Factor(s)

CTQ - Critical To Quality

CWQC - Company Wide Quality Control

DBR - Drum-Buffer-Rope

DFSS - Design For Six Sigma

DMAIC - Define-Measure-Analyze-Improve-Control

DMADV - Define-Measure-Analyze-Design-Verify

DOE - Design Of Experiments

DPMO - Defects Per Million Opportunities

EFQM - European Foundation of Quality Management

FMEA - Failure Mode and Effects Analysis

FRT - Future Reality Tree

GE - General Electric

IMVP - International Motor Vehicle Program

JIT - Just-In-Time

JTQC - Japanese Total Quality Control

JUSE - Japanese Union of Scientists and Engineers

KPIs - Key Performance Indicators

LSS - Lean Six Sigma

MIT - Massachusetts Institute of Technology

MRP I - Material Requirements Planning

MRP II - Manufacturing Resources Planning

PDCA (PDSA) - Plan-Do-Check-Act (Plan-Do-Study-Act)

POOGI - Process Of Ongoing Improvement

QDC - Quick Die Change

S-DBR - Simplified-Drum-Buffer-Rope

SMED - Single-Minute Exchange of Die

SoPQ - System of Profound Knowledge

SQC - Statistical Quality Control

SME - Small and Medium Enterprises

TLS - Theory of Constraints, Lean and Six Sigma

TOC - Theory of Constraints

TP - Thinking Processes

TPM - Total Productive Maintenance

TPS - Toyota Production System

TQM - Total Quality Management

TWI - Training Within Industry [service]

UDE - Undesirable Effect(s)

UK - United Kingdom

US[A] - United States [of America]

VSM - Value Stream Mapping

WIP - Work In Progress / Work In Process

I. Introduction

1.1. The Human Roots of Continuous Improvement

In the ancient Vedic Sanskrit language, the word for "war", *gavisti*, literally translates to "a desire for more cows".

Over 3200 years ago, in the pastoral period of Vedic society, cattle were the main source of wealth. Like any form of wealth, however, cattle were scarce. This meant that a tribe looking to become wealthier, or simply more powerful, would have to go to war with a neighboring tribe over their cattle.

It's understandable that if you had only a few meager cows and you were to see your neighbor living large because he had more cows than you, then you would seek to have a better life as well. And if you were unable to find ownerless cows roaming around in the nearest plains and no ox to even consider breeding, your only option would be to take possession of your neighbor's cows. You would probably try stealing them first, which wouldn't go unnoticed and pretty soon you would have sparked a war.

How well you would fare in such a war would depend on the quality of your weapons, your shields, your tactics, your training and your experience. If you were overall a better warrior than your neighbor, you would win, if you were worse, you would die. Either way, only one winner would emerge, gathering up all the cows and ending up wealthier than he began, powerful enough to be the dominant force in region. At least until a new, stronger opponent came along...

Regardless of whether it is a matter of survival or motivated by greed, it is commonly accepted as fact that human beings are never satisfied with how many cows they have. It may be because your tribe won't make it through the winter if you are unable to attain new food supplies, or it may be because you envy the beads and furs worn by the leader of that other tribe and his wives, but you will always have the tendency to *desire for more*. This is simply human nature, desiring for more has always been one of the most basic motivations to drive us forward, as individuals as well as a society. It is the evolution mechanism that has led us to become the dominant species on the planet, through both constructive and destructive ways.

But nothing in life comes free, so if your tribe wants more then they have to work for it, and since other tribes want the same as yours, working for it means fighting for it. If one is looking to acquire more wealth, the need for struggle is unavoidable. Competition arises naturally, for all tribes are composed of humans who will do everything in their power to maintain what they have and to attain more.

However, not everybody can win, only the best will emerge as victors. You can only expect to beat the competition if you are better than they are, at least in some respects of whichever kind of war is being fought. If you are not better, you need to become better. You need to make a conscientious effort towards becoming stronger and gaining competitive advantages over your competitors. In other words, you need to *improve* your war machine. *Improving* is thus seen as a fairly obvious requirement for victory, and rightly so. This is also why *improvements* in things such as technology, organization management or team tactics are a commonly known by-product of war and certainly one of the few positive ones.

Since the competing tribes will also be looking to improve their fighting techniques, their weaponry or their tactics, then in order to stay ahead of the pack, the leading tribe cannot rely on singular, occasional improvements. Instead, they must constantly strive to become better and better at what they do. In other words, it is not just improving that is necessary to victory, but to do it *continuously* as well. It seems logical to assume that the winning tribe will likely be the one that most vigorously pursues continuous improvement in all they do.

1.2. Motivation and Objectives

It is the same in any war, whether it's an armed conflict in ancient Vedic society or a competition between rival automobile companies in the 21st century. In modern capitalist society, wars such as this happen all the time. Companies compete for customers to gain a bigger share of the market, in order to turn a bigger profit, since their ultimate goal is to make money. To achieve this goal they need to have more sales, thereby increasing their top-line, and they need to cut costs to raise their bottom-line, which in reality just means that if they wish to improve their performance, they need to improve the way they operate. This is clearly never as simple as it may sound, for as we often find, most companies fail at this. Why?

There are certainly many reasons and, evidently, each case is unique and has its own peculiarities, but one can speculate on the most common reasons for failing at improving. To begin with, some managers do not realize the need for any improvement and run their company under the belief that the current way of operating is as good as it will ever be. In general, this quickly leads to stagnation, falling far behind competitors and all-around negative results. This usually only happens in companies run by inexperienced managers.

In some other companies, attempts are made at improving processes or technologies, or at investing in human capital, but only sporadically. These improvements are isolated, scattered throughout time and are frequently unconnected, following no common goal between them. The strategy here relies on the common misconception that one or two big investments in improvements every other year is more than enough for the company to remain competitive and have an edge over its rivals. Although they are aware of the need for improvement, they neglect doing it continuously. Some of these companies will show a poorer performance each year, trailing behind their opponents and requiring bigger investments each year just to survive. Other companies, in less competitive markets, may remain profitable, but their profit is never as high as it could be, since they are under the fake impression that enough improvements have been made.

Then we have companies that are well aware of the need for continuous improvement and strive to achieve it. However, only some of them are successful when implementing improvement or quality programs. Many others find their efforts failing, but have trouble figuring out why. Managers are often frustrated that even though they have tried to put in place some sort of methodology for their company to improve systematically, rather than achieving a new level of excellence, improvements in processes and performance were scarce and ineffective. Results were hardly better than in companies that have no such programs. How could it be?

Situations such as these lead to a multitude of questions being raised about continuous improvement methodologies and philosophies. Practitioners must first learn about the existing methodologies and philosophies and what distinguishes them. Do we need continuous improvement? Has continuous improvement ever really helped an enterprise to recover from economic crisis such as the one we are living today? Is there a continuous improvement methodology that can be considered the best? And how do I choose one for my company? Will its impact be significant? Does Lean Six Sigma produce significant results? What general guidelines or rules are imperative that we follow for the success of our continuous improvement initiative?

The motivation to write a dissertation on this subject came from questions such as these, coupled with a desire to understand how continuous improvement influences organizations and, most of all, the desire to find what industrial engineers and managers should focus on for the successful implementation of a continuous improvement system.

The aim of this dissertation is thus to provide some answers for the above questions, as well as others, or at least attempt to. By examining the history of quality engineering and management, we try to find how continuous improvement developed over time, specifically how the most common methodologies, Lean thinking and Six Sigma, evolved from concepts such as Total Quality Management and thus came to be. We try to find the roots of these improvement currents - their past - in order to understand what they are today.

History certainly provides precious lessons that we must take into account when developing a continuous improvement system. Some of these are universal truths that we must take as rules for it to be successful.

We proceed by summarizing and analyzing the defining characteristics of some of the most well spread methodologies and what makes them unique. As will be shown, Lean thinking and Six Sigma are currently being combined into a single, potentially more effective approach, Lean Six Sigma, which is arguably the state of the art in continuous improvement. The expected benefits of this system are discussed, as well as its flaws, by exposing some case studies of its implementation in the real world.

The analysis and comparison of the different methodologies and of the reasons for their success helps reveal fundamental truths that are common to all paradigms, regardless of the organization adopting them. These truths are helpful in defining guidelines for the implementation of any continuous improvement initiative.

Since continuous improvement methodologies are permanently being developed, some speculation is necessary regarding what the future of this field might be. By looking at some emerging trends, an educated guess on which direction continuous improvement will evolve in is presented.

Finally, based on what is learned from previous chapters, an attempt is made to identify the ideas and principles are common to all successfully implemented continuous improvement systems. Although the methodologies and philosophies differ vastly between them, there are certainly some underlying concepts cross-cutting through all of them. The objective is to propose a possible framework of mandatory guidelines and rules — in one word, "commandments" — for managers to follow when they are set about to embark on a continuous improvement adventure.

1.3. A Note on Work Methodology

An appropriate field study on the selected subject of this dissertation would require an extensive field survey of organizations of varying dimension and operating across different industries in order to yield reliable results — i.e. results that served as basis for a set of guidelines or commandments for the successful implementation of a CI system. Such a survey would call for significant financial and institutional backing, as well as other resources. Therefore, the work methodology chosen in alternative consisted mainly on extensively researching the endless literature on continuous improvement.

A systematic literary review was undertaken over the course of 18 months, focusing on all subjects revolving around continuous improvement: its history; cultures; main developers; abandoned methodologies; methodologies currently in use or in development; critical success factors; historical, social and geographical influences; impact on top-line and bottom-line results; impact on growth; impact on customer happiness; case studies; among many others. Close to 400 references were considered and analyzed, including books, scientific articles, media articles, conference and academic presentations, interviews and online resources.

This was done in order to paint an accurate picture of the past, present and future of continuous improvement and to firmly support the proposed commandments for successful implementation.

II. Defining Continuous Improvement

A quick review of the literature immediately reveals numerous attempts to define continuous improvement (CI). Although some of the definitions put forward share a similar basis, others differ greatly in their focus and description. Authors have referred to CI either as a philosophy, a culture, a process, a type of change, an effort or a combination thereof. Depending on context, any or all of these may be accurate.

That which is possibly the simplest definition came from Dr. W. Edwards Deming, a pioneer in the field of CI, "improvement initiatives that increase successes and reduce failures" (Juergensen, 2000). Deming clearly stated the end goal of CI in its most essential form: more successes and fewer failures. Martichenko's view (2004) resembles Deming's, "continuous improvement is about improving organizational performance".

Bessant *et al*. (1994) defined CI as "a company-wide process of focused and continuous incremental innovation". Boer *et al*. (2000) share an identical view of CI as a process, describing it as "the planned, organized and systematic process of ongoing, incremental and company-wide change of existing practices aimed at improving company performance". In a certain way, CI can be a *meta-process*, a process that transforms other processes into better ones. However, this is not always the case, as it can also be focused on improving products and services, which is referred to in other definitions.

Both authors make use of the term *company-wide*, meaning that every employee in the organization is expected to be involved in the pursuit of CI. Both definitions also stress the *incremental*, cumulative nature of CI, which generally consists of many small changes towards long-term improvement goals. These two characteristics are very much in line with the Japanese concept of *kaizen*, which is commonly translated as *continuous improvement*. In the Japanese industry, kaizen is more than just a process, it is a working philosophy, a culture shared by virtually all workers. Nevertheless, continuous improvement in its most ample sense also contemplates the possibility of large, breakthrough changes, although these are less common. It can also be an effort undertaken by a small group of people within the organization, despite it being generally acknowledged that improvement efforts stand a better chance of success if everyone is involved.

By contrast, the definition given by the American Society for Quality[a] (ASQ) distinguishes between incremental and breakthrough improvements, both of which may be sought after: "Continuous improvement is an ongoing effort to improve products, services or processes. These efforts can seek “incremental” improvement over time or “breakthrough” improvement all at once". The use of the term *ongoing* in definitions of CI is recurrent and

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[a] http://asq.org/learn-about-quality/continuous-improvement/overview/overview.html

underscores the permanently in progress state that is one of the most essential traits of a *CI* philosophy.

Fryer *et al.* (2007) employ the same term and returns to the kaizen notion that CI is the responsibility of everyone: "CI is where all members of the organization work together on an ongoing basis improving processes and reducing errors to improve overall performance for the customer". Bhuiyan and Baghel (2005) take a comparable stance in regards to reducing errors for the benefit of the customers, defining CI as a "culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization". Waste is everything that does not add value for the customer. Thus, the authors equate eliminating waste with improving. Yet, this concept of improving is somewhat reductionist. Improving a product, for example, can mean adding value to it in some way and may not necessarily mean eliminating waste. This choice of words is possibly due to the definition's focus on the continuous improvement of systems and processes. In the same manner, several definitions disregard products and services as a possible focus for CI initiatives.

The UK's Chartered Quality Institute[a] (CQI) views CI as a type of change "focused on increasing the effectiveness and/or efficiency of an organisation to fulfil its policy and objectives. Improvement in business strategy, business results, customer, employee and supplier relationships can be subject to continual improvement". The CQI definition extends the scope of CI beyond processes, products and services, by encompassing relationships with all stakeholders, not just customers. Also interesting is the use of the term *continual* rather than *continuous*.

The CQI adds that, "put simply, [CI] means ‘getting better all the time’". Indeed, if the point is to get a message across to employees from all levels of the organization, it is best to use layman's terms, free of jargon, to describe continuous improvement in the simplest way possible: getting better all the time.

On a final note, the American Society for Quality and other sources distinguish between the interchangeably used English terms: *continual improvement* and *continuous improvement*. The broader term *continual* improvement, preferred by Dr. Deming, refers to general improvement processes and "discontinuous" improvements (different approaches covering different areas). *Continuous* improvement would more accurately describe a subset of continual improvement, with a more specific focus on linear improving within an existing process and usually associated with techniques of Statistical Process Control. In this context, linguistic prescription advises the usage of the word *continual* as it pertains to things that continue in discrete jumps, as opposed to those that continue uninterruptedly. However, *continuous improvement* endures as the more commonly used term in management and industrial engineering contexts, and therefore will be the expression used throughout the remainder this dissertation.

[a] http://www.thecqi.org/Knowledge-Hub/Resources/Factsheets/Continual-improvement/

III. History of Continuous Improvement

Continuous improvement is far from being a modern day invention. Ever since the Stone Age, improvement fundamentals have been applied to all sorts of activities in order to better our way of life.

Around five centuries ago, long before the Industrial Revolution, the Venetian Arsenal was mass-producing warships and merchant ships at an extremely fast pace, reaching the rate of nearly one ship per day at the peak of its efficiency in the 16th century. At the time, if a similar sized ship were to be built anywhere else in Europe, it would take several months before it was finished.

The Venetians developed methods to make production faster, such as the frame-first system, which required less wood and, consequently, less time. But most interestingly, production operated on an assembly-line manner, as the ships were moved down the canal and fitted along the way. Division of labor was also common, as production was divided into stages and each of these had specialized workers. The layout of this enormous complex of shipyards was adapted so that there was a minimal handling of materials during production, therefore reducing waste, much like lean factories do today. Also worth mentioning is that the Arsenal was also one of the first places where standardized, interchangeable parts were used. Hence, it is no wonder that the Arsenal is seen as one of the earliest large-scale industrial enterprises in history (Cameron and Neal, 2003).

Over a millennium before the Venetians, the Romans constructed monuments and built weapons years ahead of their time, by employing new and improved materials, equipment and work systems, following what the ancient Greeks had done before them and effectively improving on it. Many of their most important landmarks are still standing today.

Perhaps even more impressively, the Egyptians, long before the Greeks and Romans, built the pyramids along the Nile using division of labor, standardization, gemba walks, pull systems, one piece flow, teaming, collaboration, visual management, quality at the source and many other Lean principles, about five millennia before the Toyota Production System was developed, almost an eternity before the term Lean was even thought up (Burton, 2014).

It is obvious that we cannot truly classify ancient Egypt's production system as Lean, just as the Venetian mass-production of vessels in the sixteenth century was far from the Ford's mass-production of automobiles in the early twentieth century. However, the idea of progressively increasing productivity by developing and putting in effect new processes, methods and technologies is not a modern one. In fact, this idea may have been one of the drivers behind mankind's progress from the birth of civilization onwards. What can be considered modern is the development of systems and methods for systematically improving the way we produce.

The industrial revolution came about in the late 18th century, early 19th century. As is well known, it was made possible by numerous scientific advances, which turned into dramatic improvements in technologies and processes. This allowed for faster production times, lower costs and better quality. Many small companies that took the risk of betting on such new technologies would soon turn into large operations, usually annihilating the more skeptic competition in the process. As mass production was born towards the end of the 19th century, craft manufacturing was virtually killed. Never before had manufacturers realized how the idea of constantly seeking to improve your business was so evidently important. Engineers and entrepreneurs in general thus began to devise ways by which to produce better products and to do so faster and cheaper. Eventually, paradigms and methodologies of continuous improvement would be developed in order to facilitate how companies improve their business, such as Lean thinking and Six Sigma.

Further ahead, this work will delve into these methodologies to give us a deeper look at each of them, but firstly let us take a look at how improvement evolved from the early periods of the industrial revolution until today.

3.1. Evolutions of Improvement

According to Burton (2014), the Western world has gone through three major evolutions of continuous improvement: engineered improvement, scientific improvement and program-based improvement. The history of each evolution is recounted next.

3.1.1. Engineered Improvement: 1780-1880

With the beginning of the Industrial Revolution in Europe and America came the first evolution of improvement: engineered improvement. This period lasted roughly from the 1780s to the 1880s and was marked by events such as the harnessing of the power of water, the beginning of standardization and, most importantly, the development of organizational strategies to increase productivity.

In the beginning, manufacturing of certain products was dependent on hand-made *outwork systems* (also known as *putting-out system*, *workshop system*, or *domestic system*). Numerous individual shops, contracted by a central agent, would be responsible for building the many small parts that made up a larger production process. For a while, this craft-manufacturing system worked well for textile industries or shoemaking, but this strategy was still quite limited. There was a need to produce on a greater scale and to have a more efficient organization of both workforce and production.

This need, supported by the increasing use of machinery, would lead to the creation of the *factory system*, the single most impactful organizational breakthrough of this period. With the advent of the factory, manufacturing was now almost entirely executed in single centralized locations on a much larger scale and this meant there would be significant economies of scale. Since the output per worker was much higher, the cost of production lowered considerably.

Unlike the practice of most small workshops, division of labor was one of the distinguishing features of factory production. Large tasks were divided into smaller tasks and given to workers dedicated to each single task, accordingly. As such, most of the workers employed in factories were either low-skilled laborers, specializing in a single task such as operating machinery, or unskilled laborers, in charge of moving around materials or finished goods. Only a few workers, such as mechanics, were completely skilled in their roles. This use of unskilled/low-skilled labor was in deep contrast with craft manufacturers, where highly skilled craftsmen would frequently create an item from start to finish.

Standardization also became common practice in factories. With a view to maximize quality, compatibility and interoperability, the production of components was done according to standard specifications. This was partly made possible due to the technological advances in machinery. High-precision machines, as well as the fact that management had a greater concern with overseeing quality, made uniformity of parts a reality that could not have been hoped for by craft workshops hand-making their products (Thomson, 1989).

With standardization came interchangeability. Interchangeable parts made assembly of new devices, as well as the repair of existing ones, much easier and faster. Workers were no longer required to fill and fit each part together as skilled craftsmen previously had to do. The skill and time necessary to execute the process were thus tremendously minimized. Because of this, the concept of interchangeable parts was critical to the introduction of the assembly line and the development of mass manufacturing (Womack *et al.*, 1990), as will be addressed further ahead.

A steady and more abundant supply of products manufactured in factories, and the fact that each unit of production was cheaper to make and sell, meant that products were more easily available to a much larger crowd of consumers. Soon the lower classes were purchasing products that were previously exclusive to the upper classes, one of the positive consequences of the factory system.

On the other hand, unable to compete with the prices and quality of factories, the small workshops dedicated to craft manufacturing were inevitably going out of business, which caused much turmoil in 19th century society. In effect, as it gave way to mass production, craft manufacturing was nearly eradicated. Only a very small number of companies, mostly focused on certain niches such as luxury hand-made items, would survive (Womack *et al.*, 1990). Rolls-Royce Motors is a good example of this.

Briefly looking at the changes that the factory system brought along with it, its impact becomes obvious, not just on the nature of manufacturing but also on global economics and society.

3.1.2. Scientific Improvement: 1880-1980

Around the beginning of the 20th Century, the world saw the birth of scientific management and the discipline of industrial engineering. It was at this time that division of labor, progressive assembly lines, standard methods and waste reduction came to be.

Frederick W. Taylor, the father of scientific management (also known as Taylorism), began observing individual workers and work methods. He believed that by analyzing work, one could determine the best way to execute it. Taylor would lay down the fundamental principles of large-scale manufacturing through assembly-line factories in his 1911 book, "Principles of Scientific Management". He advocated that managers should strive for maximum efficiency from both machine and worker and for the maximization of profit in order to benefit both workers and management. His methodology for improving production efficiency deconstructs every action or task into small and simple work elements, making them easier to analyze and teach (Taylor, 1911).

The basic fundamentals of Taylorism were:

- Maximizing job fragmentation to minimize skill requirements and job learning time;
- Separates execution of work from work planning;
- Separates direct labor from indirect labor;
- Replaces rule of thumb productivity estimates with precise measurements;
- Introduces time and motion study for optimum job performance, cost accounting and workstation design;
- Makes possible payment-by-result method of wage of determination.

Taylor was aiming to eliminate or reduce waste by employing scientific principles. Applying science to management would certainly lead to a step up in performance. However, Taylor's scientific management completely ignored the behavioral sciences, overlooking what today is called the *soft human factors* of improvement. Workers were seen as mindless, expendable and replaceable assets, not much different from the cogwheels of a large machine.

After its peak of influence in the 1910's, scientific management as a distinct theory would become obsolete in the 1930's (Woodham, 1997). However, many of its aspects would be integrated in later management theories and are still important today.

Along with Taylor, Frank and Lillian Gilbreth were among the originators of the idea of eliminating waste, a key principle in today's Lean Manufacturing. The Gilbreths supplemented

Taylor's work in time and motion studies by creating a system for subdividing worker motions into 18 kinds of elemental motions, called *therbligs* (Gilbreth in reverse), to aid in the study of motion economy in the workplace. The therblig units simplified the analysis of a process, thus making it easier to optimize manual labor by eliminating unneeded movements according to the results (Gilbreth, 1948).

Frank Gilbreth was also the inventor of Process Charting, first introduced in the early 1900's. By visually depicting the sequence of events to produce an outcome, process charts are focused on all work elements, including the non-value added elements (waste). It sometimes includes additional information such as cycle time, inventory and equipment information. Although old, it remains one of the simplest and most valuable techniques for streamlining work.

Lillian Gilbreth, Frank's wife, also studied the motivations of workers and how attitudes affected the outcome of a process. Believing that Taylor's scientific management failed to manage the human element (Graham, 1998), the Gilbreths were the early pioneers of workplace psychology.

One of the earliest conscious attempts to continuously improve the organization was done at the Bell System of companies, led by the Bell Telephone Company. For every activity and process performed by the organization, Bell managers defined results, performance, quality and costs and also set an annual improvement goal. Every year, the performance of all operations and divisions was compared to one another and the best would become the standard that all of them would have to reach the following year. Bell System was indeed among the pioneers and first developers of benchmarking.

One of the people that worked at Bell Labs, and made some of the most important contributions to today's improvement methods and techniques, was Walter Shewhart. When Dr. Shewhart started his work at the Western Electric Company, quality control was limited to the inspection of finished products and the removal of defective units. He would change that in 1924 when he first defined the major principles and considerations of what would later be known as *process quality control*. He was the first to distinguish between *assignable-cause* variation and *chance-cause* variation, terms that he originated, and he introduced the *control chart,* to determine which was which. The control chart remains one of the most widely used statistical tools today. Shewhart argued that in order to predict future output and manage a process economically, it was necessary to put it in a state of statistical control and maintaining it that way, thus avoiding unusual, unpredictable variation (assignable-cause variation) (Shewhart, 1931).

Shewhart furthered statistical quality and engineering techniques and developed the Plan-Do-Check-Act (PDCA) cycle, which was later popularized by W. Edwards Deming. Both his control chart and the DMAIC, a more contemporary version of the PDCA cycle, are among the techniques used in Six Sigma. Due to his contributions, Shewhart is frequently called the father of statistical quality control.

Lastly, it is inevitable to talk about the rise of mass production and its two major promoters in the automotive industry, Henry Ford and Alfred P. Sloan. As stated by Womack *et al.* (1990), after World War I, these two men "moved world manufacture from centuries of craft production into the age of mass production".

Although there are some examples of mass production before the Industrial Revolution, it only became widespread in the late 19th century, when its huge impact on economics first began to show. Henry Ford is usually regarded as the father of mass production, and rightly so. He was one of the originators of progressive, uninterrupted flow manufacturing, which was achieved by arranging people, machines, tooling and products in a continuous system with the purpose of manufacturing the famous Model T, introduced in 1908. Rather than having workers move at their own pace from car to car, the workers stayed in their place while a moving conveyor belt advanced the cars forward at a speed adjusted by management. This naturally accelerated the flow of work, while also preventing the workers from soldiering as they performed their tasks. Swiftness no longer depended on worker motivation.

Ford, much like Taylor, thought the average worker wanted a job in which they do not have to think. His management also used time studies and experiments to mechanize factory processes, putting great effort into minimizing worker movements. However, Ford went beyond Taylorism, striving to increase the efficiency of machines as much as the efficiency of workers. Regardless of similarities, Ford attached little importance to the role of Taylorism in the establishment of his company's mass production methods.

Thanks to these moving assembly lines, everyone was kept in motion, coordinated with impressive precision and synchronicity. It is no wonder then that Henry Ford is viewed as one of the first practitioners of Just In Time and Lean Manufacturing, or at least some of its elements. However, unlike Lean companies today, the Ford system lacked flexibility, allowing for little customization, and found it hard to adapt to annual model changes (Womack *et al.*, 1990).

By the mid 1930's, despite the fact that the Ford Motor Company made automobiles affordable to the masses, it would be surpassed by General Motors as the dominators of the automotive industry. This was mostly thanks to the pragmatic approach of Alfred P. Sloan, who applied group technology and cellular thinking to organizations, leading GM to be decentralized into independent market/product business units. He also supervised the use of thorough financial and statistical analysis tools to profitably manage GM.

This strategy allowed for greater diversity of products, that followed a hierarchical pricing structure, the "ladder of success" for consumers. This way, Sloan prevented the different brands under the GM umbrella from competing with each other and managed to gather a much larger consumer base, from small buyers to wealthy ones. Sloan's introduction of annual styling changes is also part of the reason for GM's success, as it was a clear advantage over rivals such as Ford whose rigid production system made model changes a hard process (Womack *et al.*, 1990).

It is clear that the improvements that these two visionaries were responsible for were quite different in nature. Sloan is particularly renowned for his innovation on the management side of the business, while Ford revolutionized factory floors forever.

Mass production would prove vital for Allied victory in World War II. Weapons, vehicles and supplies, whoever developed them the fastest and produce them in greater quantities would win, and the experience of automakers made all the difference. A good example of this is that of the Willow Run factory. At the time, factories were struggling to produce a single B-24 bomber per day. Charles Sorensen, Ford's right-hand man, visited the Consolidated Aircraft bomber plant and noticed how each and every plane was custom-made in a manner not much different from Ford's Piquette Avenue plant 35 years before, when the best orderly sequence was far from achieved. So Sorensen proposed a design for a new plant with a progressive layout, applying the basic fundamentals of Ford's high-volume production to break down the plane into its essential units, which were to be delivered to the assembly line in their proper sequence. The result was the Willow Run bomber plant that would turn out a bomber per hour, reaching a total of 8800 planes by the end of the war.

In 1920s Japan, while Ford was improving on his mass production methods, Sakichi Toyoda, founder of Toyota Industries, was developing weaving devices such as an automatic power loom that stopped itself when a problem occurred. This was the first implementation of the principle of autonomous automation, also known as *Jidoka,* an important part of what would later become the Toyota Production System. He also created the concept of the *5 Whys*, a common improvement technique today, particularly as part of lean methodologies. In order to get to the root of a problem, the question "why?" should be asked five times (or as many as necessary), so that some solution can be put in place to correct the cause and thus prevent the problem from recurring. For Toyoda, this would certainly be more effective than merely finding ways to quickly fix the consequences of a repeating issue.

By the end of World War II, however, Toyota was nearly bankrupt, as were all other companies in Japan. The Japanese economy was in ruins and facing huge obstacles on their road to recovery, which western economies were not burdened with, in particular:

- Higher raw material costs - few natural resources meant these would have to be imported;

- Rigid salary ranges - due to the stifling union system imposed by the Allied occupation;

- Smaller internal demand - result of the difficulties induced by the economic crisis after the defeat in WWII (Chiarini, 2012).

The Allied victory was supported by massive quantities of material supplied by the well-oiled mass production war machine in the US, and that caught the eye of the Japanese industrialists. However, given the aforementioned conditions, they could not compete with the West. Simply copying the mass production methods of western manufacturers would not fit their economic reality at the time. Soon, Japanese industries came to realize that their recovery was highly dependent upon CI methodologies of the West.

During the war, the US government created the "Training Within Industry" service (also known as TWI) to boost the industrial output on a national scale, which included job instructions, job relations and job methods training, a program aimed at training supervisors in CI methods. Management experts like Deming and Juran and the US occupation forces later introduced TWI programs in Japan (Bhuiyan and Baghel, 2005). These programs were very well received and would form the basis for the Kaizen culture in Japanese industry.

Kaizen is the Japanese term for *continuous improvement*, but a more direct translation would be *change (kai) for the better (zen*). The first use of the word kaizen in this context came from the title of a film used to introduce the three TWI "J" programs, titles "Improvement in 4 Steps", or in Japanese, "Kaizen eno Yon Dankai" (Imai, 1986). More than just a concept, kaizen is a system that involves all employees in a company. Everyone from upper management to janitors is encouraged to suggest new improvement possibilities regularly. This idea that every employee has the responsibility to contribute to a larger effort and that all suggestions are welcome became deeply ingrained in Japanese culture and is considered one of the main reasons for the post-WWII recovery and industrial success (Khan, 2011).

Dr. W. Edwards Deming is commonly regarded as the pioneer of the concept of kaizen in Japan, for which the Japanese Emperor awarded him with the Order Medal of the Sacred Treasure in 1960. Deming was an American statistician and engineer, who had been asked to provide a seminar in Japan on Statistical Quality Control (SQC) that would serve as the kick-off of the quality movement in the country. Later, he worked closely with the leaders of Japanese industry and trained hundreds of engineers, managers and scholars in statistical process control and concepts of quality. His stance that improving quality would reduce expenses while increasing productivity and market share would heavily influence Japan's chief executives. His work is frequently credited with inspiring the Japanese post-war economic miracle in the 1950's, and for this the Japanese Union of Scientists and Engineers (JUSE) honored him with the establishment of the Deming Prize, one of the most important prizes that can be awarded to a company.

Like Deming, many other quality experts gave their contribution and influenced the development of continuous improvement in Japan for the next few decades. Such was the case of Joseph M. Juran, who was disseminating Bell Labs' statistical quality control innovations before WWII and later taught courses on the subject, while running seminars for industry executives. His 1951 book, "Quality Control Handbook", earned him an invitation by JUSE to serve as a consultant in Japan. Juran gave many major contributions to the field of quality and continuous improvement, among which stand out the *Pareto principle* of defect reduction, top and middle management involvement, the need for widespread training in quality, the definition of quality as "fitness for use" and the project-by-project approach to quality improvement (Juran, 2004).

Another key figure in the development of quality initiatives in Japan was Kaoru Ishikawa, who was responsible for integrating and expanding the management concepts of W. Edwards Deming and Joseph M. Juran into the Japanese system. He is best known for formalizing the idea of the *quality circle*, which had been in practice in companies like Toyota at least since the 1950's, and introducing it in conjunction with JUSE in 1962. The concept was centered on having a group of workers who do similar work meet regularly to identify, analyze and solve work-related problems. It grew in popularity, reaching its peak around 1978, when it was claimed that there were over 1 million circles in Japan involving around 10 million workers. They continue to exist today, mostly in the form of kaizen groups. One of the quality improvement tools used in quality circles is the *cause-and-effect diagram* also developed by Ishikawa, for which he is renowned outside Japan. It is also known as fishbone diagram or simply Ishikawa diagram, and is incorporated today in Lean and Six Sigma for use in the analysis of industrial processes.

Following the visits of Deming and Juran, Japan implemented Statistical Quality Control with some positive results, but realized it was not enough. The focus had to be widened from quality of products to quality of all issues. For SQC to be truly effective, it had to be applied to the entire company, from top to bottom, a total system approach as Armand V. Feigenbaum had advocated in his 1961 book, *Total Quality Control*. With the organizational contributions of Ishikawa, a new movement began and developed between 1955 and 1960, the Company Wide Quality Control (CWQC) [a]. It was characterized by company-wide participation from top management to the lower-ranking employees. Quality control, once used only in the manufacturing process, evolved into a management tool for ongoing improvement involving everyone in an organization.

It was in this Japanese context of quality revolution that the Toyota Production System was born. In 1950, when engineer Eiji Toyoda (cousin to Kiichiro Toyoda, founder of Toyota Motor Corporation) visited Ford's Rouge Complex in Detroit, his intention was to learn about Ford's production methods so he could implement them back in Japan. At the time, while Toyota had managed to produce no more than 2,685 automobiles in 13 years, the Ford plant was producing at a mind-boggling rate of 7,000 automobiles per day (Womack *et al.*, 1990). Unsurprisingly, Eiji was in awe with the scale of the facility, however, he noticed many inefficiencies.

Back in Japan, Eiji Toyoda and Taiichi Ohno, a brilliant industrial engineer, tried to figure how to copy and improve the methods of the Rouge Complex, but soon realized that mass production at that scale would never work in Japan. Aside from the reasons mentioned earlier, the domestic automobile market was quite small and demanded a wide variety of vehicles,

[a] CWQC is usually equated with Japanese Total Quality Control (JTQC).

from luxury cars to small cars, large trucks and small trucks. Since production quantities were so small, dedicating all the equipment necessary to a single product as was done in Ford's assembly lines could not be justified. A well-known solution in similar situations would be to resort to craft production methods, as many companies did, but instead, Ohno persisted on the idea of using lines.

Ford's lines were very inflexible, in the sense that they did not handle product changes well, as it would take an extreme amount of time to change the machines' setup, days or weeks, in some cases even months. Looking to gain flexibility that would allow him to produce different components with the same machines without *wasting* time, Ohno set out to reduce machine setup times with the help of Shigeo Shingo, another major contributor. In a few years, they managed to reduce the time required to change dies on a stamping press from a day to a mere three minutes. This was known as *Quick Die Change* (QDC), although later Shingo renamed it *Single-Minute Exchange of Die* (SMED) (Shingo, 1985).

While developing ways to reduce setup times, Ohno realized that the cost per part when making small batches was significantly less than when producing huge lots, which was in deep contrast with the beliefs of mass-production. This was firstly due to the fact that small batches eliminated the carrying cost of large inventories and secondly because manufacturing only a few parts meant that defects would be detected much sooner. This discovery would have tremendous impact, as it would lead to a dramatic drop in the number of defective parts in Toyota plants.

Reduced setup times, small batches, low inventories and quality flowing from the production process, not inspection, are all characteristic of TPS (and of Lean). All of these are in line with the *Just-In-Time* (JIT) production ideal that Ohno was trying to achieve. The Just-In-Time concept had first been outlined in the 1930's by Kiichiro Toyoda, Sakichi's son, when the company ventured into automobile manufacturing. It is best described as: making only what is needed, only when it is needed, and only in the amount that is needed. In Kiichiro's system, each process produced only the kinds and quantities of items that the next process in the sequence needed and only when it needed them. Production and transport took place simultaneously and synchronously throughout the production sequence.

Taiichi Ohno focused his efforts on perfecting JIT. He began experimenting with reversing the stream of information, by pulling material into his workshop rather than pushing it. He famously took inspiration from supermarkets after one of his visits to the US (self-service grocery stores did not yet exist in Japan at the time). Ohno marveled how customers could pick the exact items they wanted in the quantities they needed, and how the empty space in the shelves would trigger the supermarket staff to replenish them at the right time in the required amount. It was a proper JIT system and Ohno realized this was the mechanism he needed.

So in order to coordinate the flow of parts, he designed the *kanban* system. Through the use of instruction cards (kanban in Japanese), a work center signals the preceding work center to start producing, as it will be requiring more components soon. Put simply, the kanban system guides the operation when to produce and when not produce, effectively preventing overproduction. In other words, each work center or line became both the "customer" for the preceding work center/line and the "supermarket" for the succeeding work center/line. Kanban is, therefore, a *pull system*, dictated by the needs of the customers located downstream - essentially, the opposite of the *push* philosophy of mass production (Goldratt, 2008).

Initially, Ohno's ideas faced great resistance and until the early 1960's his system was known internally as "the abominable Ohno system" (Ohno and Mito, 1988). It took great vision, determination and over three decades of hard work to truly reach success, a period that Toyota spent honing and perfecting its production system, relying on a dedicated workforce with a kaizen mentality to make improvement after improvement on every aspect of production. In order to improve flow and reach his goal of a perfect JIT system, Ohno also identified seven types of *muda* or *waste*. Waste can be defined as everything that does not generate value for customers, it is that which the customers are not willing to pay for and therefore should be eliminated or reduced.

Improving flow and eliminating waste thus became the organization-wide goal ingrained in Toyota's company culture and became the focus on the mind of every employee. Much thanks to the individual responsibility that every worker felt toward his job, the TPS was slowly but steadily fine-tuned into an impressively efficient production system, much above the standards of western automobile manufacturers. Despite this, the hard work at Toyota did not attract much notice until 1980.

3.1.3. Program-based Improvement: 1880-1980

After the end of WWII, while the manufacturers in a devastated Japan had no choice but to pay close attention to the quality gurus and keep busy improving every detail of their operations, the western countries, the US in particular, had little obstacles to face and instead enjoyed a period of economic prosperity, known as the *postwar economic boom* or *Golden Age of Capitalism*. From 1945 until the early 1970's, thanks to the increase in purchasing power, mass production thrived and developed unchecked. Almost everyone was now able to buy a car or a TV.

However, the American and European markets reached mass product saturation by the end of the 1960's, and instead consumers began demanding higher quality, reliability, diversity, personalized products, faster deliveries, etc. The beginning of the following decade then brought the 1971 collapse of the Breton Woods monetary system, the 1973 oil crisis mainly due to the Arab-Israeli conflict and the 1973-1974 stock market crash, all of which brought the economic boom to an end and led to the 1970's recession (Chiarini, 2012).

By then, Japan had emerged as a significant economic power in spheres such as automobile manufacturing, electronics and steelworking, and its products were now more competitive, outshining western products in every aspect, which up until a few years before had never been the case. They had spent the previous decades developing ways to eliminate waste, improve quality and respond to client demand for personalized products at competitive prices. By comparison, the mass production methods of the West were outdated in many ways, with high levels of inefficiency and inflexibility. The illusion that the economic breeze would last forever made western industry passive and unconcerned about improving efficiency, flexibility and overall competitiveness. Ironically, western gurus like Deming and Juran who had heavily influenced the Japanese quality movement and management in general were hardly recognized in their home country. Even though the Japanese were also experiencing the effects of recession, their industry clearly had a head start over their western counterparts. By the end of the decade, while European and American economies and industry had declined, Japan was a leader and its industrial and economic example was the one to follow.

The western response came in several forms. In Europe, protectionist policies were adopted, which in the long term had the negative side effect of slowing development. The US opted for a reorganization policy, cutting back on production costs, mainly on labor costs, and increasing automation (Chiarini, 2012). Beginning in the 80's, the concept of Computer Integrated Manufacturing (CIM) became popular. The idea of replacing most of the workforce with reliable robots and in return getting a faster, less error-prone manufacturing was quite appealing to managers.

The outburst of computer science also ignited the widespread use of management software, as more and more companies implemented Material Requirements Planning (MRP I) systems. Joseph Orlicky had originally developed MRP as a response to TPS practices in 1964, and then, in 1983, Oliver Wight further expanded it into Manufacturing Resources Planning (MRP II).

At the same time, organizations started hiring quality consultants and establishing quality training programs for their employees. Gradually studying and applying the proven quality control techniques used by the thriving Japanese industry, they came to realize that quality control and continuous improvement were the source of competitive advantages. It was in this context that Total Quality Management (TQM) began taking shape.

One of the first uses of the term TQM was by the US Navy in 1985. A year before, the Navy asked a group of civilian researchers for a recommendation on how to improve its operational effectiveness, based on their assessment of SPC and the work of distinguished quality consultants. They advised following the work of W. Edwards Deming and the resulting quality initiative was called Total Quality Management. In the years that followed, other branches of the US Government and armed forces would adopt TQM, such as the Department of Defense, the Army and the Coast Guard. They were soon mimicked by the private sector that was hoping to gain back market share previously lost to Japanese manufacturers and also because private companies were vying for contracts with the US federal government.

TQM drew heavily from the Japanese version of Total Quality Control, commonly referred to in Japan as Company Wide Quality Control. Coincidentally, in Japanese, the word for "management", *kanri*, also means "control". The term "management" was preferred due to the growing idea that quality has to be managed, not just controlled (Martinez-Lorente *et al.*, 1998). TQM is indeed about "the management of quality at every stage of operations, from planning and design through self-inspection, to continual process monitoring for improvement opportunities" (Anvari *et al.*, 2011). Although there is no widespread agreement on the definition of TQM and on how organizations should approach it, it is frequently mentioned that "the customer becomes the main focus of business, quality becomes the responsibility of everyone in the organization, and continuous improvement becomes the normal operating procedure" (Margavio *et al.*, 1995). TQM practitioners make use of a large number of quality control tools such as the Shewhart/Deming's *PDCA cycle* or the *seven basic tools of quality*.

Even though TQM spread like wildfire all across the US, Europe and parts of Asia, there was much confusion about which practices, policies and activities an organization had to adopt to be branded a true TQM-run business. During the 1990's, several European standards bodies made attempts to standardize quality management systems and TQM in particular. However, it was the ISO 9000 series of standards, first published in 1987 that prevailed over the others. The fundamentals defined in ISO 9000 and the requirements stated in ISO 9001 clearly specify the principles and processes that comprise TQM.

It is also important to mention ISO 9004, which "provides guidance to management for achieving sustained success of any organization in a complex, demanding, and ever changing environment", in other words, it focuses on the continuous improvement aspect of management. The focus of ISO 9004 is wider than that of ISO 9001, as "it addresses the needs and expectations of all interested parties and their satisfaction, by the systematic and continual improvement of the organization’s performance", according to the American Society for Quality[a]. Over the years, the ISO 9000 series of standards have undergone regular revisions, the latest of which was in 2015.

In the same year ISO 9000 was first released, 1987, the US federal government created the Malcolm Baldrige National Quality Award. It was aimed at making both public and private organizations more aware of the importance of overall organizational quality to become and remain competitive and encourage them to adopt its model. Quality experts, such as Joseph Juran, regard the award as the first clearly defined TQM model, and its judging criteria as the most widely accepted description of what TQM entails (Juran, 1995). Other similarly modeled

[a] http://asq.org/learn-about-quality/total-quality-management/overview/overview.html

awards were created in Europe, such as the European Quality Award, developed by the European Foundation of Quality Management (EFQM), in 1992.

According to the National Institute of Standards and Technology, in order to be awarded a Baldrige Award, an organization must have a role-model organizational management system that ensures continuous improvement in delivering products and/or services, demonstrates efficient and effective operations, and provides a way of engaging and responding to customers and other stakeholders. In 1988, Motorola, a multinational telecommunications giant, fulfilled these requirements in an exemplary manner and became the first recipient of the award.

Previously, in 1979, Motorola executive Art Sundry proclaimed at a management meeting, "The real problem [...] is that our quality stinks!" This started a new era for the company that led to the realization that the common belief that higher quality means higher costs was wrong. If quality were improved the right way, then high-quality products would cost less to produce, not more.

At the time, Motorola was spending up to 20% of annual revenues correcting poor quality, which meant a staggering loss of $US800-$US900 million each year. Bill Smith, one of the many engineers at the company, came to the conclusion that preventing defects by improving the manufacturing process and the product design would be far more beneficial than detecting and fixing defects afterwards, and also avoid the need for repair or rework every time a product failed shortly after a customer began using it. This pushed the company into trying to improve quality while simultaneously reducing production time and costs, which they did by focusing on how the product was designed and made. The initiative undertaken in 1985 was named *Six Sigma*.

The name chosen for the approach pertained to the goal the company had set for themselves in regard to reducing defects: for a given critical to quality characteristic (CTQ), engineers aimed for a level of six standard deviations (**σ** - sigma) between the process mean and the nearest specification limit, meaning that, in a single product, the average opportunity for a defect of a CTQ is only 3.4 defects per *million opportunities* (DPMO). This is the same as saying that virtually no items will fail to meet specifications which is an almost utopic objective, extremely hard to achieve. This contrasted deeply with what companies historically targeted, four sigma: 6,210 defects per million opportunities (Harry and Schroeder, 2000).

Six Sigma made the company proactive, rather than reactive. Problems had to be prevented, not fixed after the fact. The main focus of Six Sigma is on eliminating variation in processes and thus meet customer expectations while achieving immediate cost savings. In order to do this, the team in charge of improving the process makes use of the DMAIC problem-solving approach, inspired by the PDCA cycle. The DMAIC cycle stands for Define-Measure-Analyze-Implement-Control. Originally just "MAIC", it was developed by Mikel Harry and Bill Smith (the two main contributors to Six Sigma), with the "Define" stage being added later at General Electric. Six Sigma also requires the establishment of a special infrastructure of people in the organization, whose roles take their name from martial arts terms, such as Green Belt or Black Belt, that serve to distinguish each worker's Six Sigma skills, another of Mikel Harry's developments.

Motorola's strategy worked. Within the first four years, the savings resulting from the Six Sigma efforts amounted to $US2.2 billion and from 1987 to 1997 savings would total $US14 billion, coupled with a fivefold growth in sales (Klefsjö *et al.*, 2001). Producing higher-quality products at a cheaper cost translated into happier customers and bottom-line growth. In the years that followed, these results sparked an interest from other organizations in Motorola's methods. In the mid 1990's, Larry Bossidy and Jack Welch famously adopted Six Sigma for their companies, AlliedSignal and General Electric (GE) respectively, with incredible results and contributed to the further development of its philosophy and methodology. Jack Welch, in particular, seeing the opportunity to reach savings of up to $US10 billion if quality at GE was raised to Six Sigma level, promoted the methodology aggressively and enjoyed great success.

Most of Six Sigma's empirical and statistical methods were not new. Many quality experts agree that that six sigma took TQM and built on it, taking it a step further. The statistical methods, the problem solving process, the importance of top management commitment, employee involvement and others were already present in TQM (Näslund, 2008), but Six Sigma gave it a proper structure, that allows organizations to systematically pursue continuous and breakthrough improvements (Andersson *et al.*, 2006).

The 1980's and the early 1990's constituted a period ripe with contributions to the fields of continuous improvement, quality control and management in general, although many failed to convince managers of their benefits or effectiveness. Examples of this include: Business Process Reengineering, Matrix Management, Theory Z, One-minute Management, and others. Most of these were criticized as they turned out to be little more than management fads, and hardly made any relevant or long-lasting impact on organizations.

It was also at this time that Dr. Deming put forward his *14 Points for Management* in his 1982 groundbreaking book *Out of the* Crisis, fourteen key principles for improving business effectiveness. This was to be followed by another book in 1993, *The New Economics for Industry, Government and Education*, which expounded his theory of a *System of Profound Knowledge* (SoPK). By tying together his "theories and teachings on quality, management and leadership into four interrelated area: appreciation for a system, knowledge of variation, theory of knowledge and psychology", Deming provides "a framework of thought and action for any leader wishing to transform and create a thriving organization, with the aim for everybody to win". SoPK is the culmination of Deming's lifelong work (Deming, 1993), however, few organizations are known to have put it into practice and there is little research on the subject.

A more lasting contribution to management and continuous improvement came in 1984 with the publishing of Eliyahu M. Goldratt's book *The Goal*, which is regarded today as one of the most influential management books. Goldratt, who was a clear advocate of the Socratic method, wrote the management-oriented novel as a way to introduce his *Theory of Constraints* (TOC). TOC postulates that every system has always at least one (or at most a few) limiting factor, which prevents the organization from achieving its goal — for an organization, the goal is usually profit. This factor is also referred to as *constraint* or *bottleneck*. Once a constraint is identified, it can be exploited and the system can be restructured around it. If the constraint is elevated to the point that it is no longer the system's limiting factor, the cycle for improvement can start over (Goldratt, 1984). In short, TOC is a management philosophy that provides a way to systematically focus improvement efforts on the elements that most need improving, leading to a faster, continuous growth.

Moreover, TOC's ideas require that industrial engineers and managers "think about [...] problems and solutions, goals and objectives, policies, procedures and measures, *in a different way*" (Mabin and Balderstone, 1999). In fact, TOC brings with it *throughput accounting*, an alternative to the traditional cost accounting, which Goldratt criticized. It also implies taking counterintuitive courses of action, such as abolishing local efficiencies, which can actually improve the bottom line, as Goldratt's characters show in the novel. This and other notions of TOC converge with some of the views on production lines of both Henry Ford and Taiichi Ohno, whose work Goldratt credited and was influenced by.

Due to the fact that TOC defies common sense in many ways and due to a lack of case studies correlating implementation and improved financial performance, Goldratt's theory was slow to grow in acceptance and is yet to be widely recognized as a theory, although it has been gaining renewed attention in recent years, as more companies begin implementing it.

Meanwhile, at the Massachusetts Institute of Technology (MIT), in the US, there was a growing desire to undertake a detailed study of the new Japanese techniques in the automobile industry. Supported not only by auto companies, but also by governments concerned with their outdated motor-vehicle industries, a new initiative was born, the International Motor Vehicle Program (IMVP). From roughly 1984 to 1990, the IMVP launched into an extensive research, surveying over ninety auto assembly plants in fifteen countries. Sponsored by thirty-six separate organizations, both public and private, the $US5 million endeavor was possibly the most comprehensive ever undertaken in any industry (Womack *et al.*, 1990).

Based on the intimate knowledge gained from their five-year immersion in the automobile manufacturing world, the researchers James P. Womack, Daniel T. Jones and Daniel Roos decided not to just summarize their findings in a dry academic report. Instead, they wrote a book that was to have major impact in management and industries worldwide, *The Machine That Changed the World*. The book discussed the rise and decline of mass production and introduced the concept of *lean production* to the western world, at the time largely unknown. John Krafcik, one of the researchers involved in study, had coined the term *lean* a little earlier in 1988, by which he meant that lean production results in less of everything — less human effort, manufacturing space, investment in tools, engineering hours to develop a new product, needed inventory on site, etc — and also results in many fewer defects, while allowing for a much greater variety of products.

Later, in 1996, Womack and Jones followed up with another book, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. The concept of *lean thinking* expanded on the concept of *lean manufacturing* by applying the principles of lean to the whole of the organization. The term *thinking* also referred to the need to challenge the underlying thinking of organizations and changing it, rather than simply making use of lean tools.

Lean production and philosophy is, of course, derived from the Toyota Production System, which is its primary example. Despite the fact that it had been relentlessly developed and perfected over the previous 40 years, western industries still knew little about the TPS. The book shed light on the concepts and thinking behind it, sparking a worldwide interest in Lean. However, as the concept of Lean thinking grew, it expanded upon the TPS to include non-manufacturing organizations of all kinds. It also became more centered on waste elimination while Toyota's approach, referred to as the *Toyota Way*, is more focused on improving the flow of production. There may be some other differences, mostly as consequences of a poor understanding of the TPS (Liker, 2004).

As the 1990's advanced and Toyota's escalating success drew more and more attention to their practices, an increasing number of companies chose to implement Lean programs and applied it to their operations to some extent. Although some failed to obtain results, many others saw their Lean efforts return millions in savings, reducing lead times and improving product quality. Despite some criticisms, the overall consensus was that Lean was a better, smart way to run an organization. At the same time, Six Sigma programs were also growing in popularity, especially after GE implemented it in 1995, investing over $US500 million in training, an investment that clearly paid off when they reported record savings of $US12 billion after the first five years (Harry and Schroeder, 2000). TQM programs, on the other hand, progressively faded as Lean and Six Sigma rose in popularity, although they never completely went away.

In the early 2000's, practitioners began viewing Lean and Six Sigma as complimentary disciplines, which could and should be combined to attain greater business and operational excellence. The resulting hybrid methodology is referred to as Lean Six Sigma (LSS) or sometimes as Lean Sigma, and it can be traced to Michael George's 2002 book, *Lean Six Sigma: Combining Six Sigma with Lean Speed*. Since then several companies have implemented LSS in some way, such as GE, IBM, Honeywell, Verizon, Xerox, etc.

Because Lean focuses on eliminating waste and improving process flow, and Six Sigma looks to reduce variation by bringing processes into statistical control, the merging of the two methodologies is expected to have greater benefits than either of them has individually. However, to accomplish this, Lean and Six Sigma must be integrated harmoniously, as isolated implementations of each methodology within the same organization tend to create separate subcultures and competition between the two, possibly causing them to be less than effective. By opposition, a complete fusion of Lean and Six Sigma can help organizations maximize their potential for improvement.

Today, as in recent years, LSS can surely be regarded as the state of the art in continuous improvement programs and is bound to remain that way in years to come (Gack, 2007). Nevertheless, CI paradigms and methods are in permanent evolution, responding and adapting every time that economy and industry show signs of change. With a growing body of literature comparing TOC with Lean and other methodologies, authors are beginning to suggest the integration of TOC with LSS (Spector, 2006), as TOC would be employed as a focusing mechanism to apply Lean techniques and Six Sigma techniques in order to maximize the results for the organization. According to all indications, the hybrid methodologies trend will continue in the near future.

3.3. A Few Lessons from History

When looking at the history of quality control and continuous improvement, numerous lessons, both big and small, can be learned on these subjects. Mass production, for instance, taught us many things. To give a small example, according to Womack *et al.* (1990), "the key to mass production wasn't [...] the moving, or continuous, assembly line. *Rather, it was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other*. These were the manufacturing innovations that made the assembly line possible." Achieving true interchangeability of parts can indeed be classified as a great improvement, as it opened the way for the assembly line, which was another major improvement.

By 1908, Ford's assembly line made it possible that the assembler's average task cycle was 514 minutes. But Ford realized that by delivering the parts to each workstation, rather than having the worker fetch them himself, would drastically improve the task cycle. Then it was decided that each assembler would perform only a single task and move from vehicle to vehicle around the assembly hall. By 1913, the average task cycle was down from 514 minutes to a mere 2.3 minutes, an astounding improvement.

Many managers and industrial engineers would be satisfied with this achievement, and would hardly believe it could be improved on, but not Henry Ford. He brilliantly introduced the moving, continuous assembly line, making workers stationary while the car was brought to them. This further reduced cycle time from 2.3 to 1.19 minutes.

A few conclusions can be drawn on this. Firstly, more often than not, an improvement is developed on the back of another. Assembly lines were made possible due to the development of perfect interchangeability of parts, and afterwards the implementation of the assembly line gave way to other improvements such as assigning a single task per worker, delivery of parts to the workstations and finally movement was added to the assembly line itself. In other words, a single improvement can, and often will, open the way for other improvements.

This is somewhat in line with Eliyahu Goldratt's Theory of Constraints, as will be shown further ahead. The removal of a constraint (i.e. the improvement) can sometimes create the next constraint that managers and engineers will have to deal with. Even if it does not reveal a new limiting factor, once the capacity of a bottleneck is increased to the point where it is no longer a constraint, it may still be in everyone's best interest to increase its capacity further and thus prevent it from becoming a constraint again later in time, as is the case with the example of the moving assembly line improvement (Goldratt, 1984).

Secondly, mass production is the result of a very large number of improvements, only a few of which were mentioned here. The above quote from Womack is an attempt to dispel the myth that the assembly line was the major advancement that made mass production possible, instead giving credit to the interchangeability of parts. However, although that may have been one of the keys, without the many other improvements made by Ford (and others), the average task cycle time would not have been brought so low and production would amount to only a few hundred cars a year, not thousands. Surely, had the wheel never been invented, cars would not exist today, but four wheels alone do not make up a car. In an industry, all improvements are important, whether they are done to achieve mass production or some other objective.

Why does this matter? Attributing the success of an enterprise to a single improvement, such as the assembly line or interchangeability of parts, perpetuates the false notion that one good idea or innovation is enough to improve a company's operations and achieve success. And this is the reason for the failure of many improvement efforts. In other words, only a constant pursuit of perfection — continuous improvement, that is — will grant meaningful results. This is the idea that should be spread among managers.

And thirdly, as Ford proved when he reduced the average cycle time from 2.3 to 1.19 minutes, regardless of how efficient a process becomes, there is almost always room for further improvement. With industries being as competitive as they are today, every minute (and every cent) counts. Jumping to the conclusion that a process is so efficient that it cannot be made better is clearly a mistake, albeit a common one.

The history of Japan and its post-war economic miracle also taught us much. When nations and industries go through periods of great distress and are struggling to regain competitiveness is usually when they make the greatest breakthroughs. The simple fact is that times of *need* stimulate countries and industries to innovate on all levels. Innovations can be new policies, new products, new ways of producing, marketing and, of course, managing. In the past, it was at times like these that CI philosophies and methods took the greatest leaps. Such was the case with the development of Japanese TQC and the Toyota

Production System, new paths to pursue quality and efficiency, born from the ruins of a war-torn economy.

On the other hand, it is important to note that the specific circumstances of Japanese post-war economy, with particular regard to the low levels of demand, are what led to the TPS, a vastly different way of producing when compared to mass production. No company could afford to produce mass quantities of products to achieve a lower cost per item if there was no one to sell them to. Since economies of scale were out of the question, Taiichi Ohno and Eiji Toyoda realized that production had to be driven by sales and success depended on finding ways to reduce costs, which led to the pull system and JIT manufacturing. Other Japanese companies came to the same conclusion, mass-production methods of the West could not be copied and instead they had to focus on becoming progressively more efficient, in ways that Western organizations were not. It is reasonable to assume that, in most scenarios, organizations that want to improve must adapt and respond directly to their environment. In short, a different reality requires an original approach.

However, Japanese industry did not recover over night. It was a long road to success, as organizations had to persist in their improvement efforts for decades before they paid off. Analogously to the Ford Motor Company, it was improving little by little, relentlessly, that Japanese organizations became highly efficient. Toyota's success was the result of thousands of improvements. Continuous improvement was once again proven to be a long-term journey, or even a never-ending one.

In the West, the decline of mass production, the 1970's economic crisis and the industry's loss of competitiveness were hard to face but opened the way for a decade filled with new management ideas. In like manner to what had happened in Japan after WWII, the western industries' desperate need for solutions propelled a vast number of CI initiatives and developments in the 1980's. Once again, adverse circumstances provided the fuel for a revolution in management.

The subsequent recovery of Western economies, just as was the case in Japan, points to the crucial role of continuous improvement in turning industries around. In these instances, as in the rise of mass production at the beginning of the 20th century, the development of new CI methodologies was followed by economic prosperity. Although there are certainly many other factors contributing a nation's growth, progress seems to be intertwined with continuous improvement.

Lastly, it is interesting that TQM, Six Sigma and other advances were based on existing methodologies, such as Japan's CWQC or Walter Shewhart's statistical process control methods. Likewise, the TPS (and, consequently, Lean) was partly inspired by Ford's mass production methods. Previous developments in CI paradigms are not discarded and instead serve as foundations to new paradigms and methodologies. Ironically, the permanent evolution of continuous improvement implies that it is itself subject to continuous improvement.

IV. Paradigms and Methodologies

This chapter is dedicated to the present-day CI paradigms and methodologies that are deemed the most effective, and thus have become the most widely adopted: Lean, Six Sigma, Theory of Constraints and Lean Six Sigma.

Although all of the above have the same common goal, they have very different natures that must be distinguished. The first of these, Lean, refers to a way of thinking, of which continuous improvement is an essential piece, which impacts the whole organization and shapes the entire production system. Six Sigma is a systematic, structured approach to tackling particular problems within the organization. It uses a set of methods and techniques to retrieve data, analyze it and subsequently improve the process at hand. TOC is a systems theory that helps managers look at the entire system and tells them where to target improvement efforts first and how to organize production accordingly. Lastly, Lean Six Sigma combines the concepts and tools of Lean with those of Six Sigma.

It is important to understand that all of these approaches are simultaneously paradigms and methodologies. A paradigm can be defined as "an entire constellation of beliefs, values and techniques, and so on, shared by the members of a given community" (Kuhn, 1996), or in other words, it is guided by an underlying philosophy. A methodology is a structured set of guidelines or activities, which embodies the philosophical assumptions of the paradigm under which it was developed (Mingers and Brocklesby, 1997). A methodology in turn can be decomposed down to a set of techniques, which can best be described as specific activities with a clear and well-defined purpose.

The following sections attempt to expose the philosophy behind each of the approaches and the methodology each one uses to achieve its objectives.

4.1. Lean

Lean is much more than just a CI methodology: it is an entire business management philosophy. Many companies choose to implement only some of its tools in isolation, with the purpose of quickly improving processes through the elimination of obvious wastes and thus gain immediate short-term profits. They generally do so with limited success, if any, as Lean's conceptual model is intended to shape the whole organization around it, both its operations and its structure (Liker, 2004). Proponents of Lean argue that success is achieved as a result of the long-term effort to sculpt a lean organization.

The Lean philosophy and methodology is based on, and evolved from, the Toyota Production System. It was initially referred to as Lean Manufacturing or Lean Production, but later as the concept expanded to include its application to all facets of the organization (and since it can just as well be adopted by non-manufacturing organizations), it became known as Lean

Thinking or simply Lean. The term "lean" was chosen to describe the TPS because it needs "less of everything": inventory, space, investment in tools, human effort, hours in development, etc. It also means fewer defects and more flexibility and productivity. So it makes sense that the term "lean" stands for both "slim" and "elegant".

Lean and TPS are also sometimes called Just-In-Time Manufacturing or Production. However, some authors prefer to view JIT as only one element of a broader philosophy (together with Jidoka, they are said to make up the two main conceptual pillars of the TPS). For Toyota, JIT is about making only "what you need, in the amount you need, by the time you need it." Its developer, Taiichi Ohno, claimed there is another unwritten part: "at lower cost" (Ohno, 1988). It was in the pursuit of this concept that the TPS acquired its unique characteristics, such as the pull system or the continuous flow.

For the organization to achieve JIT production, and consequently become progressively lean, it is necessary to improve flow, which in turn requires the systematic elimination of waste, which is what Lean became famous for. The permanent goal is to improve overall customer value, by eliminating all activities that add no value, either directly or through fine-tuning the system to prevent the appearance of those activities.

It is supported in this quest by a number of concepts, practices, tools and techniques developed over the years, mostly at Toyota, which will be examined in the following sections. Another undeniable supporting factor is company culture, which should be geared toward continuous improvement as much as possible. Although Toyota's kaizen culture is difficult to mimic, organizations looking to implement Lean must involve all their employees in their improvement efforts and empower them to contribute from their own initiative.

Lean can thus be viewed as a paradigm, a methodology and a culture, all centered on the continuous improvement of an organization striving for perfection. To better understand the inner workings of the paradigm, the next sections examine the five principles of Lean, concepts such as kaizen and several of its practices and tools.

4.1.1. The Five Principles of Lean

After their comprehensive study of the TPS and careful reflection, Womack and Jones (1996) synthesized Lean Thinking into five major principles: 1- precisely specify *value* by specific product, 2- identify the *value stream* for each product, 3- make value *flow* without interruptions, 4- let the customer *pull* value from the producer, 5- pursue *perfection*. Clear understanding and integration of these principles is crucial to the successful implementation of a completely lean system and to making full use of lean techniques.

What follows is a brief analysis of the five Lean principles.

1. Value

The first principle of Lean Thinking requires that organizations specify *value*. Organizations' definition of value is often conditioned by "the immediate needs of shareholders and the financial mind-set of senior managers" which are looked at as its main priorities. However, it is the customers that "sustain any firm in the long term". Therefore, it is the needs of the customer that must be the main priority.

Value is what the customer wants and nothing more. It is what the customer is willing to pay for. If a product comes packed with features no one ever asked for, it is generally a sign the producer is attempting to force onto the consumers whatever it finds more convenient. It may also mean they have no clue what the consumer wants.

On the other hand, the price of a product usually reflects not just the value it holds, but also the costs of all non-value added activities undertaken before it was in the customer's hands. The customer has no wish to pay for activities such as transporting, waiting, reworking and others, all of which are deemed wasteful. To have a lean organization, this waste (or *muda* as it is called at Toyota) must be sought out and eliminated, but in order to do so, it is imperative to listen to the customer and specify value from his perspective. Value must be expressed in terms of the specific features of a product, as well as a specific price and a specific time to delivery, through a dialogue with the specific customer for whom the product is intended. This notion plainly marks lean thinking as a customer-focused approach.

Womack *et al.* explained it best when they wrote: "Value can only be defined by the ultimate customer. And it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time" (Womack and Jones, 1996).

2. Value Stream

The next step towards a lean organization is identifying the entire *value stream* for each product or product family. Womack and Jones (1996) define the value stream as "the set of all the specific actions required to bring a specific product [...] through the three critical management tasks of any business: the *problem-solving task* running from concept through detailed design and engineering to production launch, the *information management task* running from order-taking through detailed scheduling to delivery, and the *physical transformation task* proceeding from raw materials to a finished product in the hands of the customer."

When companies carry out a value stream analysis, which they rarely do, it almost always exposes huge amounts of waste. More specifically, the value stream analysis will distinguish three types of actions: 1- steps that unambiguously create value, 2- steps that create no value but are unavoidable with current technologies and assets (Type I *muda*), and 3- steps that create no value and are immediately avoidable (Type II *muda*). This distinction facilitates the removal or attenuation of non-value adding steps. The savings from disposing straight away of Type II *muda* can be dramatic, while the revelation of Type I *muda* provides a tangible medium-term/long-term goal to focus improvement efforts, which can prove fruitful in the future.

It should be noted that when defining the process stream, managers should consider the actual processes, not company departments, and also that the analysis of the value stream must not disregard the actions that take place both upstream and downstream. Often, there are redundant processes happening either on the supplier side or the customer side. This means that lean thinking should go beyond the firm, as the creation of lean enterprises requires "a new way to think about firm-to-firm relations, some simple principles for relating behavior [...] and transparency regarding all the steps taken along the value stream [...]". In other words, when working to become lean, cooperation between partner firms is paramount (Womack and Jones, 1996).

3. Flow

After mapping the value stream of products and removing needless wasteful steps, the next stage for lean is making the remaining value-creating steps flow, which usually requires a degree of cultural change.

It is a common belief that organizing work by departments and then producing batches of parts is more efficient and more easily manageable. When developing the TPS, Taiichi Ohno contradicted this belief after observing that when the product is worked on continuously from raw material to finished good, tasks are performed with greater efficiency and accuracy. For better results, it is more important to focus on the product and its needs than on the organization or the equipment, "so that all activities needed to design, order, and provide a product occur in continuous flow" (Womack and Jones, 1996).

Henry Ford realized the potential of flow and lined up all the machines to produce the Model T in a continuous flow from raw materials to the finished car. However, despite the massive success achieved, his system only worked for a single product and when the demand was measured in thousands or even millions of orders. Ohno took the idea further, by making it possible to create continuous flow in small-lot production when the need was for only a few dozens or hundreds of items. This was done by developing ways to "quickly change over tools from one product to the next and by "right-sizing" (miniaturizing) machines" so that different processes could occur adjacent to each other in tight sequence (Womack and Jones, 1996).

Flow thinking and the implicit idea that working on few pieces at a time is more efficient are counterintuitive, but undeniable. More often than not, a large batch will stand waiting for a long period of time before the next department is ready to handle it. By opposition, working on a small number of pieces or even on a single piece at a time, while seemingly inefficient, allows for a faster, uninterrupted flow that keeps the product moving. As an added benefit, it also guarantees a low level of *work in progress* (WIP).

Ideally, engineers and managers should strive for a one-piece flow, although it is quite hard to achieve and it poses some risks for production. It took Ohno and his collaborators several years of hard work to progressively reduce the size of batches and achieve greater levels of efficiency. Achieving a continuous flow is in many ways a continuous improvement challenge.

4. Pull

Once departments are converted to product teams and the size of batches progressively diminishes to allow an increasing flow, throughput times in product development, order processing and physical production are expected to drop significantly. Having now developed greater efficiency, speed and flexibility, the organization can let the customers *pull* the product, according to what they actually need.

Whereas before, a company produced according to a sales forecast, which was often inaccurate, and then pushed products onto the customer, now production can be pulled by demand, meaning that products will only be manufactured when ordered. This is made possible by the new found ability to give the customer exactly what they want and just when they want it, which in turn helps stabilize demand.

The major benefit from converting to a pull system is that it eliminates the need to hold inventory. Inventory means stacking, storing and transportation costs, which can now be cut, freeing capital for the company. There will also be no more spending with the creation of discount campaigns to get rid of goods no one is interested in.

As previously mentioned, Ohno was inspired by the way of operating of supermarkets, where shelves are replenished as customers buy the products. Likewise, to direct production when to produce, each work center signals the work centers upstream that it will soon need parts to process and supply to another work center. Toyota's pull system that triggers the movement of materials is called *kanban*, which will be explained further ahead.

5. Perfection

The last principle of lean regards the pursuit of perfection, which ties the initial four principles together. Every time flow is improved, more hidden waste is revealed in the value stream, while the pulling of the product tends to uncover previously unknown obstacles to flow. The permanent dialogue with customers makes it possible to specify value with more precision. The first four principles are interconnected in a somewhat cyclical way. Going through them regularly takes the company closer to perfection, which is what the company should strive for. This is synonymous with saying that improving should be continuous, since reaching perfection is a never-ending quest.

"It dawns on those involved that there is no end to the process of reducing effort, time, space, cost and mistakes while offering a product which is ever more nearly what the customer actually wants. Suddenly *perfection*, the fifth and final principle of lean thinking, doesn't seem like a crazy idea" (Womack and Jones, 1996).

However, striving for perfection demands the involvement of all employees. There must be a dedicated workforce with a continuous improvement mentality. For this to become a reality, it is necessary to create a new culture within the organization. At Toyota, the pervading Japanese *kaizen* culture, which is addressed next, drives workers to actively look for opportunities of improvement every day.

4.1.2. Kaizen and Kaikaku

The Japanese word *kaizen* is usually translated as *continuous improvement*, although a more accurate translation would be *change for the better*. Kaizen has its origins at Toyota and can be described as a culture or system whereby every employee in the organization is encouraged to continually look for and suggest small improvements to processes, products or services. The objective is to simultaneously eliminate waste and increase productivity, safety and effectiveness, by implementing small, incremental changes (Khan, 2011), in other words, "more value with less muda" (Womack and Jones, 1996**)**. Afterwards, results are monitored and adjusted if necessary.

Kaizen differs from other traditional CI processes in that it is mostly action-based. "They don't plan, they don't propose, they *do*" (Khan, 2011). The idea is to make changes immediately, wherever they can be made, as soon as the opportunity is revealed, no matter how small the improvement is. It is argued that in the long-term these incremental changes add up and result in a more competitive, successful organization.

In a kaizen-based organization, every employee is responsible for making improvements to the specific job he performs. This is due to the belief that the one performing job usually knows better than anyone else how to improve it, including his superiors. Nevertheless, it is common to put together teams to execute a *kaizen event* (or a *kaizen blitz*).

A kaizen event is a short duration improvement project. Lasting no more than five days, projects are focused on a particular activity or process. Most teams are given very limited budgets (typically $US300 to $US400), which serves as a stimulus to come up with creative solutions. The point of this is to get the team to find ways to improve using only the equipment and tools at hand.

One of the known critical success factors of kaizen is the need for kaizen teams to be guided by experienced practitioners that have gone through training and certification, while another is the need to narrowly define the scope and focus of kaizen projects. There must be a strong support from top management, which should not only accept the need for change, but also lead the process. On the other hand, the measurement of results must be unambiguous.

In the case of Toyota, the trust between company and employee is another deciding factor. When significant productivity improvements displace workers, Toyota does not let workers go or demote them. Instead, they seek alternative value-added work for them to perform. Going for the typically western approach of laying off employees that are no longer necessary would cause animosity and undercut kaizen efforts, as workers would fear creating improvements that would render their position obsolete and cost them their job (Liker, 2004). Trust and pride in the company, on the other hand, can be powerful motivators.

The benefits of kaizen are clearly worth the effort. To give an example, in a single year, 7,000 employees at a Toyota plant proposed over 75,000 ideas for improvement, of which 99% were implemented. Such a huge amount of improvements often results in higher productivity and quality, lower costs, faster delivery, better safety, and increased customer satisfaction. Additionally, employees find their job easier and more enjoyable. The more they help the company become more successful, the more job security they have, which coupled with management's recognition of their efforts translates into higher employee moral, higher job satisfaction and lower employee turn-over (Khan, 2011).

A less talked about concept, also originated at Toyota, is that of *kaikaku*. While kaizen refers to *incremental changes*, the term kaikaku is translated as *radical change* (or more accurately, *reform*). Unlike kaizen, which is about many minor, gradual changes that are slow to affect the system, kaikaku concerns the execution of rapid, drastic shifts that have a large immediate impact on the organization. Switching from a push to a pull system of production, for instance, is the kaikaku type of change, a complete paradigm reversal.

Contrary to kaizen, since kaikaku is about introducing new knowledge, strategies, approaches, techniques or equipment, and given that it has a significant impact on the business, it is almost always initiated by management. A radical change can be triggered by external factors, such as the appearance of new technology or the changing of market conditions, or it can be management's response when current kaizen efforts are stagnated and showing poor results. Once concluded, it will have formed a new base for kaizen activities (Womack and Jones, 1996).

Kaizen initiatives normally result in improvements close to 20%, while kaikaku results are in the range of 30-50%. Nonetheless, kaizen, being about gradual, incremental changes suggested by employees at all levels, is a more alien concept to western organizations, whereas swift, substantial changes are a more common occurrence, even if not carried out in the same manner as kaikaku at Toyota.

However, although significant transformations have to take place, breakthroughs do not happen in one big step. Vast changes result in unstable environments, which require sustained, step-by-step improvements to reach stability. This is why both kaizen and kaikaku are a mandatory part of a company's culture to attain the best possible results. As Womack *et al.* put it, "[...] the combination of *kaikaku* and *kaizen* can produce endless improvements" (Womack and Jones, 1996).

4.1.3. Eliminating Waste

In spite of Lean being well known for its focus on the systematic elimination of waste to increase profitability, the idea of doing so was spawned long before the development of the TPS and the rise of lean manufacturing. Instead, Toyota can take credit for expanding the notion of waste, which today encompasses much more than just scrap material or excessive worker motions. It stands to reason that the more we can identify as waste, the more potential for improvement there is.

So what is waste? Lean proponents usually describe waste as "any human activity which absorbs resources but creates no value" (Womack and Jones, 1996) or a similar expression, and is often referred to by the equivalent Japanese term, *muda*. Muda is the most discussed type of waste in lean literature. However, there are two other broad types of waste defined by Toyota, *muri* and *mura* (Liker, 2004). These two types of waste are just as important as muda, if not more, and are usually the hidden causes from which the muda in processes is derived.

The following is a closer look at the three M's, as they are often called.

1. Mura

Mura stands for *unevenness* or inconsistency. Unevenness pertains mainly to the fluctuation between times when there is lack of work and times when there is more work that can be handled by either people or machines (Liker, 2004). Common causes for this include customer demand, varying process times per product, variation of cycle times for different operators, irregular production schedules and unsteady production volumes due to internal problems, such as downtime, missing parts or defects.

Mura requires the permanent availability of all equipment, materials and people needed for producing at maximum capacity, even when average requirements are significantly lower. This is an indicator of lack of flexibility, which is a must have in production environments with low-volume and high product variation. Naturally, when mura is not reduced, it commonly causes both muri and muda (addressed ahead). That is why eliminating unevenness can be viewed "as the resolution of the other two M's" (Liker, 2004).

Ways to reduce unevenness include leveling the schedule (*heijunka*, explained ahead), changing product design, introducing greater openness in the supply chain and standardizing work (Liker, 2004).

2. Muri

Muri refers to the *overburdening* of people or equipment. In other words, it "is pushing a machine or person beyond natural limits" (Liker, 2004). When people are overburdened, it gives rise to safety and quality issues, as well as absenteeism. When equipment is overburdened, it results in breakdowns and defects. This type of waste can be the result of mura or caused by the removal of too much muda from the processes.

Muri can be dealt with in a number of ways: implementing preventative and autonomous maintenance will help optimize the use of machines and their proper functioning; safety should be designed into all processes in order to protect employees and prevent them being overworked; and lastly, standardized work plays a major role in clearing processes of muri. To achieve a standardized process, work elements such as workflow, repeatable process steps, machine processes and takt-time must be arranged into standardized work sequences.

3. Muda

Muda is the most recognizable type of waste, and as previously mentioned, it concerns any *non-value-added* activity. These are the activities that consume resources but create no value, and as a result extend lead times, require extra movement to get parts or tools, create excess inventory or greater waiting times (Liker, 2004), which is why they should be removed as much as possible.

However, it should be added that the complete removal of all muda is unrealistic. For example, there will always a need for transportation of goods from the plant to the customers, just as there will always have to be some inventory, even if minimum.

For this reason, Muda can be divided into two main types: Muda Type I (One) and Muda Type II (Two). Type I refers to non-value-added tasks that are necessary for some reason and thus cannot be avoided. Business conditions need to change or new technologies have to be invented before these tasks can be eliminated. Type II concerns non-value-added tasks that can be targeted for elimination immediately.

Regardless of type, Taiichi Ohno distinguished between seven different kinds of muda:

1. **Transportation** - Carrying WIP over long distances, or moving materials, parts or finished goods into or out of storage or between processes.

2. **Inventory** - Excess raw material, WIP, or finished goods leading to longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. It also hides

problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime and long setup times.

3. **Motion** - Any wasted motion employees are forced to do while working, such as looking for, reaching for, walking, or stacking parts, tools, etc.

4. **Waiting** - Situations such as workers doing nothing more than watching over an automated machine, or standing around waiting for the next processing step, tool, supply, part, etc, or simply having no work because of stockouts, lot processing delays, equipment downtime and capacity bottlenecks.

5. **Over-processing** - Executing unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. It also pertains to providing products with higher quality than is necessary. Ohno considered it the fundamental muda, for it causes most of the others.

6. **Over-production** - Producing more items than have been ordered, which leads to overstaffing and storage and transportation costs due to excess inventory.

7. **Defects** - Production of defective parts and subsequent correction. Repair or rework, scrap, replacement production and inspection imply wasteful handling, time and effort (Liker, 2004).

Additional kinds of muda have been suggested, such as unused employee talent and creativity, unused by-products or processes, or the wasting resources (e.g., unused machines).

Most organizations adopting lean for the first time commit the mistake of implementing lean programs that focus on eliminating muda only. This is done because identifying and eliminating muda is the easiest approach and fastest route to obtaining immediate results. However, doing so without first understanding and targeting mura and muri, the main originators of muda, is a sure path to failure.

If, for instance, inventory was reduced along with the number of workers, as soon as customer demand spikes, the system will react by pushing people and equipment to their maximum and beyond. Stressed workers will be more prone to suffer accidents and to commit errors, breakdowns will happen more frequently, parts will tend to run out, the number of defective items will increase. In other words, the muda that had just been reduced will now rise uncontrollably. Many managers would then jump to the conclusion that lean thinking is just a management fad and has no application in their particular organization.

For lean to be truly effective, engineers and managers must first face the more difficult "task of stabilizing the system and creating *evenness*" (Liker, 2004). In other words, to achieve a balanced lean flow, the elimination of mura is the number one priority. If the work schedule is leveled (concept of *heijunka*, see next section), it will highlight the muri within the system, which can then be targeted for removal.

Eliminating mura and muri first will in turn cut the vast majority of current muda in the system and greatly prevent its creation. In short, CI efforts should be concentrated first and foremost on mura, then muri and only afterwards on muda.

4.1.4. Lean Concepts, Practices and Tools

This section describes some other popular concepts, practices and tools that organizations employ to become lean.

5s - A method for organizing the workplace so that it is suited for lean production and visual control. The term represents a set of five rules for organizing that begin with "S". *Seiri* (Sort) is about separating needed tools, parts and instructions from unneeded materials and removing the latter. *Seiton* (Set in order) concerns ordering the remaining items and identifying them for ease of use. *Seiso* (Shine) means conducting a cleanup and inspection of the area. *Seiketsu* (Standardize) means standardizing the above practices. *Shitsuke* (Sustain) means forming the habit of always following the first four S's and applying them regularly.

5 Whys - It is an iterative interrogative technique that consists of asking "why" five times whenever a problem occurs. Each question sets the basis for the next question. Its aim is to determine the root cause of the problem. Appropriate solutions can then be developed and implemented to correct the cause and stop the problem from reoccurring.

Andon - A visual feedback system, usually a lighted display placed overhead. It displays current production status, alerts team members to emergencies and empowers operators to stop the production process.

Gemba - Japanese word that means *the real place*, the place where value is added, (i.e. the manufacturing floor). It is associated with the term *Genchi Genbutsu*, Japanese for "go and see". It serves to remind that problems are visible and that management should get out of the office to visit the plant floor (known as the *gemba walk*). First-hand observation and direct interaction with plant floor employees help gain a deeper understanding of real world manufacturing issues. Some of the best improvement ideas come from gemba walks.

Heijunka - It is a technique for reducing mura, which in turn reduces muda. It creates a level schedule, by sequencing orders in a repetitive pattern and smoothing the day-to-day variations in total orders to correspond to longer-term demand. It essentially mixes product variants within the same process, resulting in smaller batches. Because each product is manufactured more frequently and batches are smaller, it reduces both lead times and inventory, respectively. Also known as **Level Scheduling**, **Production Leveling** or **Production Smoothing**.

Hoshin Kanri - A strategic decision-making tool to be used by top management to align the goals of the company (strategy) with the plans of middle management (Tactics) and the work performed on the plant floor (Action). It makes use of visual matrix diagrams to select three to five key objectives, while deselecting all others. The selected objectives are translated into specific middle management projects and then deployed down to the implementation level. It unifies and coordinates resources, establishes clearly measurable targets and monitors the progress toward the key objectives, essentially eliminating the waste that results from poor communication and inconsistent direction. Also known as **Policy Deployment**.

Jidoka - It is the concept of designing equipment to partially automate the manufacturing process and to automatically stop when defects are detected. It is based on the idea of transferring human intelligence to automated machinery so machines are able to detect any defects and immediately stop while asking for help. Workers are able to monitor multiple stations, cutting labor costs, and quality is improved by detecting quality issues early on. Also known as **Autonomation**.

Kanban - It is an inventory control system to regulate the flow of materials within the factory and with outside suppliers and customers. The word *kanban* refers to the signaling cards attached to containers that inform the upstream work center when and what to produce. When goods are needed, the cards signal upstream production to begin in order to fill the containers with the required amount and replenish the downstream work center. Kanban supports a demand-driven production, allowing the customer and downstream processes to pull products through the value stream, which classifies it as a pull system. Elimination of waste from both inventory and overproduction, as well as the promotion of improvement in the organization are among the benefits of kanban.

Key Performance Indicators (KPIs) - Lean metrics developed to track and encourage progress towards critical goals of the organization. The right selected KPIs can be very powerful drivers for behavior.

Plan-Do-Check-Act Cycle (PDCA) - An iterative four-step methodology used for the control and continuous improvement of processes and products. The "Plan" stage consists of establishing the plan and expected results. This is followed with the implementation of the plan during the "Do" stage. The "Check" stage is for verifying if the expected results were achieved. Finally, during the "Act" stage, the improvement is reviewed and assessed, and if necessary the cycle is repeated for adjustments. Also known as **Shewhart cycle**, **Deming cycle** or **Plan-Do-Study-Act (PDSA)**.

Poka-Yoke - A mistake-proofing device or procedure that helps operators avoid (*yokeru*) mistakes (*poka*), whether it is during manufacturing or order taking. Error detection and prevention is deliberately designed into production processes, due to the difficulty and expense of finding all defects at a later stage and correcting them. The goal is to achieve zero defects during production.

Takt Time - Derived from the German word *taktzeit*, best translated as *measure time*. It sets the pace of production to match the rate of customer demand, becoming the heartbeat of the system, especially if it is a lean system. It is calculated by dividing the available production time by the rate of customer demand.

Single-Minute Exchange of Dies (SMED) - A series of techniques developed by Shigeo Shingo for making changeovers of production machinery (setups) in less than ten minutes (Single-Minute actually refers to single digit: 0-9 minutes). Shorter setup times allow the manufacturing of smaller lots, reduction of WIP and improved customer responsiveness. The obvious long-term objective is to always have *zero setup*, when changeovers would be instantaneous and would not interfere in any way with continuous flow. Techniques include: converting setup to be external (done while process is running), simplifying internal setup, eliminating non-essential operations, creating standardized work instructions, and others.

Standardized work - Documented procedures describing precisely each work activity specifying cycle time, takt time, the work sequence of specific tasks, and the minimum inventory of parts on hand needed to conduct the activity. It helps eliminate waste by consistently applying the best practices. It also forms a baseline for future improvement activities. Additionally, it must be easy to change.

Total Productive Maintenance (TPM) - A holistic approach to maintenance, focusing on proactive and preventative maintenance to maximize the operational time of equipment. Its main objective is to ensure that every machine in a production process is always able to perform the required tasks so that production is never interrupted. It empowers operators to help maintain their equipment, effectively integrating maintenance with production. By encouraging greater involvement of plant floor workers, it can contribute to improvements in productivity, such as increased up time, reduced cycle times and elimination of defects.

Value Stream Mapping (VSM) - A tool used to identify and visually map all the specific activities occurring along a value stream for a product or product family. It exposes waste in current processes and allows the creation of future state maps as well as action plans to simplify work, and highlights opportunities for improvement.

Visual Factory - It refers to the placement in plain view of all tools, parts, production activities, and indicators of production system performance, so that everyone involved can keep up with the status of the system at a glance. The use of visual indicators, displays and controls improves communication of information. Also known as **Visual Control** or **Visual Management**.

4.2. Six Sigma

Harry and Schroeder (2000), two of main developers and proponents of Six Sigma, described it as "a disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and eliminating them". Linderman *et al.* (2003) defined it as "an organized and systematic method for strategic process improvement and new product and service development, that relies on statistical and scientific methods, to make dramatic reduction in customer defined defect rates". But how did this method come to be?

The Six Sigma methodology was born at Motorola out of a pressing need to increase quality. At the time there was a widely held belief that increasing quality was inevitably synonymous with increasing control costs. Motorola's engineers realized that increases in quality could, in truth, lead to decreases in costs of production. If processes are improved enough to make the number of errors close to zero, costs such as those of inspection, rework and others, the so-called Costs of Poor Quality (CPQ), will consequently drop. With that in mind, Six Sigma was developed, for the purpose of achieving higher quality while lowering costs, which in turn translates to happier customers and greater profits.

Six Sigma is known for its primary focus on reducing variation in all processes within the organization in order to eliminate defects. Process variation is a major source of defects, and is in fact what defines the *sigma* level. A six sigma level of quality is equivalent to only 3.4 defects per million opportunities or 99.99966% accuracy and the respective CPQ will amount to less than 1% of sales. By contrast, the traditional TQM optimum point of balance between the defect rate and costs of control was at four sigma, signifying a level of quality with an accuracy of 99.38% (6,210 DPMO) and CPQ in the range of 15-25% of sales.

In practice this means that a television station operating at 99% (3.8 sigma) would have 1.68 hours of dead air time per week, but if quality rose to Six Sigma levels there would be only 1.8 seconds lost per week. Operations running at 3.8 sigma may seem an acceptable level of quality for a television station, however, for airline safety this is not acceptable at all. At 3.8 sigma, or 99%, there would be 2 short or long landings at major airports *every day*, whereas at 6 sigma (99,99966%), there would be only 1 short or long landing every five years (Pande, *et al.*, 2000). Whether it is a matter of safety, customer satisfaction or preventing costs of quality to gain savings to the bottom-line, reducing variation in order to improve quality is an imperative for any organization to achieve its goals.

Table 1 - Sigma levels of quality (Source: adapted from Harry and Schroeder, 2000)

Sigma Level Yields, DPMO and the Cost of Quality			
Sigma Level	**Yield**	**Defects Per Million Opportunities**	**Cost of Quality**
1	30.85%	691,462	Not applicable
2	69.15%	308,538	Not applicable
3	93.32%	66,807	25-40% of sales
4	99.38%	6,210	15-25% of sales
5	99.977%	233	5-15% of sales
6	99.99966%	3.4	<1% of sales

Looking at the table above, it is clear to see that improving from sigma 1 to 2 will signify an increase of over 38%, but as the sigma level goes up, the gains in yield are less and less. The reason this happens is because it is much easier to improve a bad process than one already working well. The more a process is improved and the better it gets, the harder it is to improve it further (George *et al.*, 2004). Also noticeable above is that each sigma shift provides an impressive 10% net income improvement.

Similarly to TQM, Six Sigma relies on a number of statistical tools and techniques. What makes it different is that while TQM was a loose philosophy — based on the ideas of Deming, Juran, Feigenbaum, etc. — that was never unified, Six Sigma provides a systematic and structured approach to the continuous improvement of processes. Six Sigma's DMAIC project methodology, originally developed at Motorola and later refined at General Electric, is essentially an evolved version of the Shewhart/Deming cycle (PDCA/PDSA). It is used to guide improvement projects and see them through to their conclusion. Each stage builds on the previous one and the whole meta-process is cyclical in nature, repeatable as many times as necessary to attain the desired quality. Likewise, the DMADV methodology provides a step-by-step way for designing new processes that meet customers' expectation of quality.

Also unique to Six Sigma is the infrastructure of people created within the organization to promote, support and undertake improvement projects. All people involved with the Six Sigma initiative are required to undergo the appropriate training and are given a martial arts-inspired title reflecting their level of skill. The title, such as *Black Belt* or *Master Black Belt*, also denotes the role played by the employee in the organization's Six Sigma efforts.

An important feature of Six Sigma is its customer focus. Six Sigma teams always listen to the *Voice of the Customer* (VOC) at the start of every project. Before any decision is made regarding a product or service, the opinions and needs of customers have to be known. The most important features of a product or service are referred to as Critical to Quality (CTQ) requirements. Defects associated with CTQ requirements have the most impact on a business, so these features must be a priority in any Six Sigma initiative.

There are numerous examples of Six Sigma success. Many companies, large and small, have reported dramatic savings to the bottom-line, as well as improved product quality and customer satisfaction. Motorola is one of the most obvious examples, having shown $US14 billion in the first ten years of implementation. Their profits rose nearly 20% per year and sales achieved a fivefold growth. Between 1996 and 1997, General Electric invested around $US500 million in Six Sigma training, but by 1998 had savings of $US750 million and a year later saved another $US1.5 billion (Harry and Schroeder, 2000), while AlliedSignal saved over $US2 billion during a five-year period (Klefsjö *et al.*, 2001). Companies in general have reported savings around $US150,000 per Black Belt project with each Black Belt completing four to six projects per year.

With so many companies reporting such positive results, Six Sigma proponents regard it as a truly effective CI strategy and argue that although the implementation of a Six Sigma program requires a significant investment in training, the expected return on investment more than justifies it.

After the success of Six Sigma at General Electric, Jack Welch, its former CEO and one of the major promoters of the methodology, describes Six Sigma company as "... a company who is manageable, understands that variation is evil, and that serving customers with what they want, when they want it, is the key [...] Six Sigma really drives you in a methodology that allows a customer centric view, and where the understanding is deep and broad in the organization" (Jack Welch interview on Youtube[a]).

4.2.1. DMAIC and DMADV Project Methodologies

The Define-Measure-Analyze-Improve-Control (DMAIC) is a project methodology used by Six Sigma practitioners to improve an existing process. It is essentially an improvement cycle, usually described as a "structured, data-based problem-solving process" (George *et al.*, 2004). "Structured" because activities are done in a specific sequence, "data-based" because data is gathered in nearly every phase to help make decisions, and "problem-solving" because it makes sure the chosen solutions truly eliminate the cause of the problem being tackled. In short, it is a "logical flow to problem-solving" (Brook, 2006), a framework that provides the discipline and guidance to improvement teams.

DMAIC is composed of five distinct but interconnected stages[b], all of which are supported by a large set of tools. It is generally preceded by a project selection process, which is undertaken by a management team to identify which project should be launched first. At the end of each stage, a *tollgate review* is undertaken, which helps determine if all the goals in the stage have been completed and if the project is ready to move to the next stage.

The following is a brief description of each of the five stages in DMAIC as described by George *et al.* (2004) and Andersson *et al.* (2006).

1. Define

The first stage is concerned with clearly defining every determinant aspect of the project: which process/product needs improvement, project targets and boundaries, most suitable team members for the project, customers of the process, customers' needs and requirements. The project charter is usually the document that contains the above information. Tools used at this stage include: Project Charter, SIPOC diagram, Value Stream Map.

[a] http://www.youtube.com/watch?v=aNMULFcLuIM
[b] Harry and Schroeder's "Breakthrough Strategy" adds three extra stages to DMAIC, which becomes: Recognize-Define-Measure-Analyze-Improve-Control-Standardize-Integrate.

2. Measure

The purpose of this step is to identify the key factors with the most influence on the process, and deciding how they should be measured. It is at this step that data is gathered. Six Sigma is known for making informed decisions, based on data and facts, so collecting information is a vital part of the process. The performance metric baselines established at this phase will later be compared to the performance metric at the end of the project to determine how much the process has been improved. Tools used at this stage include: Process Map, Capability Analysis, Pareto Chart, Time Value Map, Time Series Plots.

3. Analyze

Once all information and data is collected, it must be analyzed so as to confirm the source of delays, waste and poor quality. The challenge here is "sticking to the data" and not jump to conclusions based solely on experience and opinions. Instead, teams must look for patterns in the data and target places with a great amount of wasted time. The objective is to identify, validate and select the root cause of variation for elimination. Tools used at this stage include: Root Cause Analysis, Failure Mode and Effects Analysis (FMEA), Multi-vari Chart, Cause-and-Effect diagrams.

4. Improve

At this point, a solution is identified, tested and implemented. Changes are made to the process aiming to eliminate the defects, waste, costs, etc., that are linked to the customer needs identified in the Define stage. it is important that the changes affect the cause previously identified in the Analyze stage. Tools used at this stage include: Design of Experiments (DOE), Kaizen Events.

5. Control

The last stage seeks to make sure that the gains obtained through improvements are sustained. This requires creating procedures and work aids to help people do their jobs differently from now on, transferring the newly acquired knowledge to the process owner and training everyone working on the process in using the new documented procedures. This will help: prevent backsliding, react quickly to future problems, share the learning with others in the organization. Tools used at this stage include: Control Plan, Statistical Process Control (SPC), 5S, Mistake-proofing (Poka-Yoke).

While DMAIC was created to improve existing manufacturing or service processes, a parallel methodology, DMADV, was developed to help design new products or processes, so as to prevent problems from ever occurring. In other words, it is about *designing things right the first time*, building Six Sigma efficiency into the process before implementation.

DMADV is also composed of five stages, Define-Measure-Analyze-Design-Verify, which have obvious similarities with those in DMAIC:

1. Define - Define the design project goals and customer deliverables.

2. Measure - Measure and determine customer needs and specifications (CTQ's).

3. Analyze - Analyze the process options to meet the customer needs.

4. Design - Design the process to meet the customer needs.

5. Verify - Verify the design performance and ability to meet customer needs.

DMADV is sometimes synonymously called Design for Six Sigma (DFSS), although DFSS is more usually viewed as a larger approach, related to Six Sigma, that aims to meet or exceed the needs of the customer and the CTQ output requirements when the product is first released (Sokovic *et al.*, 2010).

4.2.2. Six Sigma Tools

Six Sigma makes use of vast set of tools, many of which were previously deployed in TQM programs, having been developed many years or even decades before. Not all of them, however, are necessarily used in different Six Sigma initiatives, as it is common for practices to vary slightly from organization to organization. A few of the most notable tools are briefly described below.

Critical to Quality (CTQ) Tree - This tool is used during the Define stage of DMAIC. It is used to brainstorm and validate the needs and requirements of the customer of the process targeted for improvement.

Process Map - It is a graphical representation of a process, making it simpler to understand all of its steps and inner workings. Before the construction of a process map, team members must reach an agreement on the meaning of the symbols to be used and the scope. It is easy to use, provides a high-level, visual depiction of critical elements and handoffs and is useful as a training aid.

Histogram - The project team makes use of the histogram during the Analysis phase of DMAIC for reviewing data collected during the Measure stage. Having the data organized into graphs or charts makes it easier to understand what it says about the process.

Pareto Chart - While the histogram is useful for continuous data, the Pareto chart is generally preferred for the treatment of discrete data. Discrete data is counted data (go/no go, off/on, yes/no, defects/no defect). The Pareto chart is associated with the famed 80-20 rule, which in this context could mean, for example, that 20% of root causes are responsible for 80% of defects. Dealing with discrete data, it should be counted and categorized according to reason codes for why a defect occurs, so it can be represented on a Pareto chart.

Cause-Effect Diagram - Also known as Ishikawa's diagram, or fishbone diagram, it captures all the ideas of the project team regarding what they believe are the root causes behind the current sigma performance and aid in finding a root cause of the problem. With it, causes are visually grouped into major categories to help identify the sources of variation. It is sometimes considered the most important tool for determining root causation.

Scatter Diagram - After ideas have been prioritized through use of the cause-effect diagram, the project team needs to validate the remaining ideas with fact and data. This can be done through the use of a scatter diagram, which helps track data corresponding to a particular idea.

Control chart - A control chart uses collected data to determine the upper and lower control limits of a process and check if the process is in a state of statistical control. Control limits are the expected limits of variation above and below the average of the data, which should not be crossed. These limits are mathematically calculated and indicated by dotted lines. If the monitored process is not in control, improvements or corrections are needed. Analyzing the chart can help find the sources of variation.

SIPOC - SIPOC stands for Suppliers-Inputs-Process-Outputs-Customers. It can be described as a high-level picture of the process that depicts how the given process is servicing the customer. It is normally used during the Define stage of DMAIC, as it helps clearly understand the purpose and scope of a process. It serves as a starting point in identifying the Voice of the Customer (VOC) and will later aid in the construction of a detailed process map.

FMEA - FMEA is an acronym for Failure Modes and Effects Analysis. It is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. "Failure modes" regards the ways, or modes, in which something might fail. Failures are any errors or defects, especially those that affect the customer, whether potential or actual. "Effects analysis" refers to studying the consequences of those failures. FMEA's purpose is to take actions to eliminate or reduce failures, starting with the highest-priority ones, and hopefully before they happen. It is used during design to prevent failures and later it is used for control.

Design of Experiments (DOE) - DOE refers to a branch of applied statistics that deals with planning, conducting, analyzing and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. A strategically planned and executed experiment may provide a great deal of information about the effect on a response variable due to one or more factors, and it also helps avoid frequently encountered problems in analysis.

It should be noted that Six Sigma shares some of its tools with Lean, such as 5S, 5 Whys, Visual Stream Mapping, Poka-Yoke and Kaizen events, which are described in the Lean chapter.

4.2.3. Implementation Roles

Introducing Six Sigma in an organization requires the creation of specific staff roles. Some of these roles are newly created positions in the infrastructure of people while some of the existing staff maintain their regular jobs but expand their responsibilities to include Six Sigma efforts (George *et al.*, 2004). Accurately defining the role of each employee in Six Sigma removes any ambiguity regarding who is responsible for what.

The name of Six Sigma's implementation roles is famously inspired by martial-arts belt rank system. The following is a brief description of each role (George *et al.*, 2004):

Executive Leadership - Members of top management who define the vision for Six Sigma implementation. They establish the strategic focus of the Six Sigma program making sure it aligns with the organization's culture and values.

Champion - Champions are executive-level managers, responsible for managing and guiding the organization's Six Sigma initiatives so that they support and drive corporate priorities. They identify individual projects and create an organizational deployment plan that reflects the company's vision, mission, goals and metrics. They also identify resources and remove roadblocks. Champions may report directly to the CEO or to the person in charge of the business unit in which he works.

Master Black Belt - These individuals are Black Belts who went on to receive advanced training in more complex problem-solving techniques. To reach this position they must have led several project teams and have a proven track record of delivering results. They are responsible for training and coaching Black Belts and Green Belts, monitoring team progress, and aiding teams as needed. They develop key metrics and the strategic direction, and essentially act as the organization's Six Sigma technologist and internal consultant. They work exclusively on Six Sigma efforts.

Black Belt - Black Belts are responsible for leading or coaching project teams, and for delivering results on selected projects. To become a Black Belt, an employee has to receive a minimum of 4 to 5 weeks of training on leadership and problem solving. They generally work full-time on Six Sigma, although in some organizations they work only part-time. Like Master Black Belts, they work only on Six Sigma efforts.

Green Belt - Green Belts receive some level of training in Six Sigma. Although usually they maintain their regular jobs, they also work part-time on Six Sigma projects. They assist Black Belts with data collection and analysis. They also lead Green Belt projects or teams

White Belt/Yellow Belt - These individuals receive only some level of awareness in Six Sigma fundamentals. While Yellow Belts may be project team members and review process improvements, White Belts only support projects and are not part of a project team.

4.3. Theory of Constraints

Eliyahu Goldratt's Theory of Constraints is less of a theory and more of a management paradigm that provides managers with a clear focus for running and improving an organization.

Every organization, regardless of its nature, has a clear, distinct goal. The goal of profit oriented organizations is to make money, and, preferably, to keep increasing profits. But achieving that goal is rarely easy. With that in mind, TOC's founding principle is very straightforward. It postulates that every manageable system is restricted from achieving more of its goal by at least one constraint (Goldratt, 1984).

The concept of constraint can thus be defined as any factor that limits the system from realizing more of what it strives for, which is usually profit. Alternatively, constraints are also referred to as *bottlenecks*. TOC's premise that there is always at least one constraint is based on the argument that if nothing stopped the system from achieving higher throughput, then throughput would be infinite, which is inconceivable for a real-world system.

In other words, TOC sees the organization's interlinked set of processes as a chain, and that chain is only as strong as its weakest link, i.e. the constraint. Therefore, improving the constraint will have the effect of improving the entire system. This is why TOC, in a manner reminiscent of Lean, is concerned with improving flow through the constraint, for that is the only way to increase overall throughput. On a side note, in order to improve flow, TOC makes use of a special kind of accounting proposed by Goldratt, Throughput Accounting, which shall be addressed in greater detail in the following subsections, along with its specific concepts, such as throughput.

When a particular machine's process, for example, is identified as the constraint of the system and is targeted for improvement (through the Five Focusing Steps, explained in further ahead), its production capacity might be elevated to the point where it is no longer the weakest link in the chain. The constraint has been "broken" and is no longer the factor limiting the system. The constraint is now some other process. The chain is now stronger and the process can then be repeated (Goldratt, 1984). If, however, the constraint cannot be elevated immediately (or ever), it should be exploited to the maximum and the system should be subordinated to it. That means ensuring that the constraint process always works at full capacity: avoiding idle times and waiting for WIP, preventing breakdowns from occurring, finding defective items before the constraint, etc. This is what managing the constraint refers to.

The constraint may be of many types: machine, employee, shelf space, supplies, cash, etc. But regardless of its nature, correctly identifying and managing constraints is the quickest and surest way to accomplish significant improvements. Neglecting to do so, on the other hand, can prove to be an enormous waste of resources and capacity, and even a source of destabilization of the entire production. Ideally, the organization will work to elevate all internal constraints and market demand will stand as the ultimate constraint.

The interest in TOC has been slow to rise. Yet, although it is not a philosophy as widely adopted as Lean or Six Sigma, it has shown dramatic improvements and impressive results in many organizations around the world, regardless of geography or field of industry. TOC proponents claim many different benefits can be obtained from its implementation, namely: better control over operations and far less firefighting; reduced cycle times and therefore inventories; exposing additional production capacity without any investment; rapid response culture and fewer chronic conflicts between team members; elimination of stock-outs across the supply chain; On-Time In-Full delivery to customers; and higher net profit, return on capital employed and free cash flow.

According to one independent study, companies where TOC was implemented were found to have, on average, a 50% reduction of inventory, a 66% decrease of cycle-times, a 69% decrease in lead-time, an improvement of 60% in due-date performance, an increase of 68% in revenue and an astounding 82% increase in profits. Considering that in some of those companies the application of TOC tools was just partial, the impact of a full implementation could potentially be much larger (Balderstone and Mabin, n.d.).

To sum it up, the Theory of Constraints provides a way to keep improvement efforts focused and tells managers where they should be focused. It is a method for finding weaknesses in the organization and eliminating them systematically. It shifts the focus of management from the optimization of separate assets, functions and resources to the improvement of flow of throughput generated by the entire system. By using TOC's concepts and tools to manage constraints (addressed in the following sections), profits can be increased and the goal can be reached.

4.3.1. Throughput Accounting: Throughput, Inventory and Operational Expense

The term *throughput* is frequently used in TOC literature. Throughput is generally regarded as the rate of production or the rate at which something can be processed, but Goldratt's definition is somewhat different: it is the rate at which the system generates money through sales, with the keyword being *sales*, instead of production. It essentially represents all the money coming into the organization. This also means it is meant to measure the overall system, rather than measure local efficiencies, which Goldratt believes must be abolished.

Throughput is one of three measures defined by Goldratt, with the other two being *inventory*[a] and *operational expense*. Inventory is "all the money that the system has invested in purchasing things which it intends to sell". This definition of inventory includes facilities, equipment, raw material, work in process, finished goods and obsolete items. Operational expense is "all the money the system spends in order to turn inventory into throughput" (Goldratt, 1984). Examples of operation expense include direct labor, utilities, consumable supplies and depreciation of assets.

These three measures are the fundamentals of Goldratt's proposed Throughput Accounting (TA), an alternative to the traditional *cost accounting*, and an integrant part of TOC. All three measures are interdependent, meaning that changing one will cause a change in one or both of the other two. He defended that these measures alone covered everything managed at a manufacturing plant and that monitoring them allows a more accurate assessment of the organization. Through them one can determine if the goal of "making money" is being reached. Quite simply, for the organization to make money, the value of the product (and the price charged) "has to be greater than the combination of the investment in inventory and the total operational expense per unit" (Goldratt, 1984).

Another strong point is that they provide a way to relate local decisions to the performance of the entire system. Since the information provided by Throughput Accounting reports what is currently happening in operations, distribution and marketing, it is more current and therefore more relevant. Because it does not rely only on financial accounting reports that still need to be verified by external auditors, the information is of greater relevance to the ongoing decisions that management needs to make. Goldratt viewed more conventional measures — such as net profit, return on investment or cash flow — as less than useful in daily operations, and thus preferred throughput, inventory and operational expense, which more closely reflected the current performance of the organization.

In order to improve the organization (and get closer to the *goal*) using TOC, managers must follow the formula that expresses the goal in terms of Throughput Accounting: *maximize throughput, while simultaneously minimizing both inventory and operational expense*. In fact, Goldratt believed that all improvement opportunities should be prioritized by their impact on the three measures, throughput in particular, since its increase is only limited by market size. From his perspective, understanding how to make sound financial decisions based on the three measures is absolutely vital for the goal to be achieved.

[a] In later TOC documentation, the term *investment* is preferred over the term *inventory*.

4.3.2. The Five Focusing Steps of TOC

As mentioned before, the Theory of Constraints looks to improve the overall throughput by improving flow through the constraint. The cyclical process through which TOC systematically targets the organization's constraints is referred to in TOC literature as the *process of ongoing improvement* (POOGI) — essentially, another term signifying a continuous improvement process. It is a simple set of five focusing steps, which are as follows:

1. IDENTIFY the system's constraint(s)

The first and most obvious step states that if a constraint is to be managed, it must first be identified. Focusing improvement efforts on the productivity of a constraint resource leads to increased profits, whereas focusing on a non-constraint does not increase throughput, since the number of products assembled remains the same. A non-constraint process may become faster, but if the resulting WIP has to wait longer down the line, there is no overall benefit for the system — this is one of the reasons why Goldratt defended the abolishment of local efficiencies. Only the global system's efficiency truly matters. Instead, increasing throughput is only dependent on increasing flow through the constraint.

So how to identify it? A constraint is defined as anything preventing the system from achieving its goal. First of all, it is important to understand that in any system there is always at least one constraint, but never more than a few — never hundreds or thousands. Secondly, a constraint can be internal or external. If the system can produce more than the market is able to consume, then the constraint is external and the organization should look for ways to create more demand. If, instead, the market is demanding more than the system can deliver, the constraint is patently internal and improvement efforts should be focused inwards on finding it.

There are three types of internal constraints: equipment, people and policy. A piece of equipment can either be limited technologically or be currently used in such a way as to limit the system's ability to produce more products or services. As for people, their lack of training or cultural mindset can be restricting the system's productivity. Lastly, not only can a written policy be preventing the organization from achieving its goal, so can an unwritten one.

A different form of classification divides internal constraints into two kinds: physical and policy. Physical is broken down further into capacity constraints and material constraints. Capacity constraints refer to labor, machines and buildings, needed to process material into a finished product. Material constraints refer to raw goods, WIP, etc, that are to be converted to finished product.

By employing the three measures of Throughput Accounting (throughput, inventory and operational expense), it is easier to detect where the system's constraint is currently located and determine what type it is.

2. Decide how to EXPLOIT the system's constraint(s)

After identifying the constraint, the second step is about obtaining as much capability as possible from it, without undergoing expensive changes or upgrades. Capacity of the constraint is limited, so its productivity should always be at peak levels.

One possible way to do so is to avoid downtime at the constraint. A machine, for example, can be kept running during lunches, breaks and shift changes, which will add greatly to its output. Better maintenance of the machine can also prevent it from breaking down frequently, and an appropriate schedule showing the sequence in which orders are to be processed can also serve to manage the constraint and maximize its output.

3. SUBORDINATE everything else to the above decision

The non-constraint components of a system must be subordinated to the constraint operations. Their settings are to be adjusted so that they allow the constraint to operate with maximum effectiveness. The point is to ensure that the materials needed next by the constraint always show up on time. Whereas conventional practice would call for efficiencies to remain as high as possible by releasing enough material for everyone to be busy, TOC suggests that non-constraint resources should only be permitted to process enough materials to match the requirements of the constraint. This somewhat mirrors Lean's just-in-time practices.

Therefore, the release of materials should be controlled and synchronized according to the constraint schedule. Note that unlike the constraint, non-constraints do not have a schedule. Workers are instructed to begin work as soon as parts arrive at their stations, to work at a normal pace, and to immediately pass the finished parts on to the next operation. There is no point in slowing down to fill the available time. If there is no WIP to be processed, then the non-constraints operations will be idle, meaning their efficiencies will be low. However, preventing overproduction at non-constraint resources is necessary to reach the goal of making more money. Again, it becomes clearer why Goldratt frequently states that local efficiencies should be abolished. As he puts it, "A plant in which everyone is working all the time is very *inefficient*" (Goldratt, 1984).

Once the non-constraints have been adjusted properly, the constraint may have shifted to another process, making it necessary to evaluate the overall system to determine if it has or not. If the constraint has indeed been eliminated, the improvement process jumps to step five.

4. ELEVATE the system's constraint(s)

If after steps two and three, the output of the constraint is still not enough to satisfy market demand, it becomes necessary to find (or create) more capacity by *elevating* the constraint. Elevating the constraint means taking whatever action is necessary to eliminate it.

At this point, managers consider making major changes to the system. As a last resort, a new machine with greater capacity may be purchased, if the investment is justified. But first, other solutions may be tried, such as rerouting material through other machines, if possible, or resorting to an old machine that performs the same job (an example in Goldratt's *The Goal*), or even to outsource some of the work. These methods, as well as others, can significantly add extra capacity to the system.

5. Go back to step 1, but beware of INERTIA

Once the constraint's capacity as been elevated and it ceases limiting the system from having greater throughput, it is no longer the constraint. The fifth step directs change agents to go back to the first step and identify a new constraint, because there is always at least one. This is what effectively makes the process a cyclical one, and ensures that improvement will be continuous.

The sole obstacle standing in the way of continuous improvement is *inertia*. Goldratt warns practitioners against becoming complacent. TOC is meant to be an ongoing process, but the inertia that tends to naturally arise after a change is made can slow or even halt continuous improvement. Inertia itself can become an unsuspected constraint.

It should be added that because it is impossible to ever completely balance a line (there will always be a constraint in the system), the organizations that reap the greatest benefits from TOC are those that make a strategic choice of where they want the constraint to be and then manage operations accordingly. This way the constraint can be managed to the organization's advantage and not the other way around. It also means that at some point in the future, when the constraint is at its most advantageous position, management may choose not to go through the five-step process again.

4.3.3. Drum-Buffer-Rope and Buffer Management

Drum-Buffer-Rope (DBR) is an operations scheduling methodology, part of the TOC operations solution, that aims to protect the weakest link in the chain (i.e. the constraint) against process dependency and variation. Protecting the weakest link makes sure the whole system is protected, and thus its overall effectiveness is maximized. This results in a solid and dependable process, allowing the system to produce more, with less inventory, less rework/defects, and better on-time delivery. As will be explained ahead, DBR is closely related with the process of ongoing improvement, in particular with steps two and three.

The methodology is named after its three components. The *Drum* is the constraint of the system, its weakest link. It is the machine, workstation or operation preventing the system from having higher throughput. The reason it is called Drum is because it sets the pace or "beat" of the entire system, which the rest of operations must follow. As mentioned earlier, the drum or constraint must not be allowed to waste any of its capacity (step 2 of POOGI). It should never sit idly waiting for parts and its capacity should be employed only for producing the parts required to fulfil sales orders. To make sure this does not happen and to maximize the constraint's output, a Drum Schedule is created, which will provide a detailed plan for its particular area.

The non-constraints in the system must meet the Drum Schedule, and also the shipping schedule from which it is derived. Since there is always variation in the system and Murphy[a] causes unexpected breakdowns from time to time, a *Buffer* is necessary. The Buffer is meant to protect the Drum, by ensuring there is always work flowing to it. In DBR, the Buffer is a pre-determined length of time (rather than quantity or material) that dictates when the order must be released into the system before it is due on the Drum Schedule (step 3 of POOGI). By definition, all other resources (non-constraints) have more capacity than the constraint. As such, by introducing parts a buffer time before they are expected at the constraint, work will build up in front of it and protect it from breakdowns of preceding operations[b].

However, one should take care not to let too much inventory be introduced in the system. A new order must only start when the constraint finishes one. For that reason, a *Rope* is tied to the first operation of the system. The Rope is essentially the work release mechanism for the system. It is calculated by subtracting the constraint Buffer time from the date on the Drum Schedule. Thus orders are released one Buffer of time before they are due. The Rope effectively "chokes" the release of work into the system. Without it, releasing work earlier than this buffer of time would cause excess WIP and slow down the whole system.

Change agents should beware that "choking" the release of work reveals the excess capacity of non-constraints in front and behind the constraint. Afraid of not being busy all the time, non-constraints could tend to slow down, which would impact negatively on throughput and delivery performance. This must be handled in implementation to let workers know that local efficiencies are not the priority and that it is expected that some of the non-constraint resources will spend some time sitting idly.

[a] Murphy's law (also referred to as Murphy) is an adage commonly evoked in the industry, and frequently mentioned in TOC literature, that states: *Anything that can go wrong, will go wrong*.

[b] Usually there are buffers at various points in the system: at the constraint, synchronization points and at shipping points

While DBR is to be used when the constraint is internal, if the organization is only limited externally by market demand, a variation of DBR is used, called S-DBR: Simplified-Drum-Buffer-Rope. Having more capacity than there are orders to fill it, all orders should be delivered on time. S-DBR aims to guarantee that the system satisfies all orders. In this case, the Drum setting the pace of production is the market itself. This will result in the Drum Schedule being the same as the shipping schedule.

Lastly, the concept of Buffer Management must be addressed. If DBR is seen as the motor for production, then Buffer Management is the monitor. It guides managers on how to tune the motor for optimum performance. If DBR is the general way in which the system operates, Buffer Management is the monitoring system that helps make sure the effectiveness of the system is maintained.

Whenever there are disruptions or blockages during production, actions must be taken to make sure due-dates are met. Buffer Management analysis the information collected regarding possible reasons for delays and establishes priorities on the shop floor. Buffer Meetings are held for 10 minutes each day (or shift) with all relevant staff. Their objective is to focus everyone's attention on the currently important orders in the system and to check if the actions decided on the previous meetings have been completed. New actions are assigned regarding orders marked with red. Colors such as red, yellow or green are commonly used to define the priority of each order, according to how many days away delivery is.

4.3.4. Thinking Processes

The TOC Thinking Processes (TP) is a set of integrated problem-solving tools, based on rigorous cause-and-effect logic. The founding principle behind the TP is that every complex problem arises from a deeper issue - a *core conflict*. Troublesome, difficult situations happening daily are understood by employees and managers as problems, but it is more than likely that those are just symptoms of a particular core conflict. More often than not, the symptoms are only superficially treated through elaborate policies, behaviors or measurements, which minimize emergencies but do not address the real issue. Quick fixes such as these can only be temporary and must be replaced by a more permanent solution. Otherwise the core conflict will only become more serious.

The Thinking Processes guides managers in finding core conflicts and developing breakthrough solutions, by identifying, challenging and correcting unexamined assumptions. It helps managers find a few crucial answers for the pursuit of continuous improvement:

1. What to change?

2. What to change it into?

3. How to cause the change?[a]

To find unequivocal answers to the above questions, the Thinking Processes are used in a logical flow, going through a series of five steps:

1. Gain agreement on the problem
2. Gain agreement on the direction for a solution
3. Gain agreement that the solution solves the problem
4. Agree to overcome any potential negative ramifications
5. Agree to overcome any obstacles to implementation

The following is a list of some of the classic thinking process tools, which are usually applied during a two-week workshop to identify the cause-effect logic and map a detailed solution.

Current Reality Tree (CRT) - The Current Reality Tree traces the network of cause-effect relations between the undesirable effects (UDE's) to pinpoint their root cause and ultimately identify the core conflict.

Evaporating Cloud (EC) - The Evaporating Cloud, also called conflict resolution diagram is a logical diagram that articulates the core conflict clearly, diagramming the logic behind it and examining the assumptions behind the logic, to find the one supporting the conflict.

Future Reality Tree (FRT) - The Future Reality Tree maps the full implications of the proposed *injections* (actions which solve the conflict) to ensure they are sufficient to solve every UDE. It helps identify possible negative outcomes of the changes so they can be adjusted before implementation.

Negative Branch Reservation (NBR) - The Negative Branch Reservation exposes the potential negative ramifications of an injection (see FRT) through cause-effect logic, so that they can more easily be trimmed.

Transition Tree (TT) - The Transition Tree sequences in great detail the complete set of actions to get from a starting point to an end objective of implemented changes.

Prerequisite Tree (PRT) - The Prerequisite Tree is similar to the Transition Tree, but is used for more elaborate or complex undertakings. It additionally describes all of the intermediate objectives necessary to carry out an action and the obstacles in the process.

[a] Occasionally, two other questions are added: 4. Why change?; and 5. How to maintain the process of ongoing improvement?

4.4. A Comparison of Lean, Six Sigma and TOC

Understanding the differences between Lean, Six Sigma and Theory of Constraints can be helpful to choose the most adequate one for a particular organization. However, due to their very different natures, comparing the three is not a straightforward task. The following table summarizes the CI methodologies side by side, so their differences and similarities can more easily be pointed out.

Table 2 - Comparison of CI methodologies
(source: part original, part adapted from Nave, 2002, and Pacheco, 2014)

	Lean thinking	Six Sigma	Theory of Constraints
Origin	Toyota Motor Co. (1940's-1980's)	Motorola and GE (1980's)	Eliyahu Goldratt (1980's)
Theory	Remove waste	Reduce variation	Manage constraints
Ease of implementation	High difficulty	Medium difficulty	High difficulty
Hierarchical level of application	Company-wide	Technical level and middle management	Top management
Application Guidelines	1. Value 2. Value stream 3. Flow 4. Pull 5. Perfection	1. Define 2. Measure 3. Analyze 4. Improve 5. Control	1. Identify constraint 2. Exploit constraint 3. Subordinate processes 4. Elevate constraint 5. Return to step 1
Focus on	Flow	Problem	System constraints
Goal	Provide perfect value to customers	Maximize business results	Continuous increase in profits
Assumptions	- Waste removal will improve business performance; - Many small improvements are better than systems analysis.	- A problem exists; - Decisions must be based on collected data and its analysis; - System output improves if variation in all processes is reduced.	- Emphasis should be on speed and volume; - Local efficiencies are of little or no importance; - System throughput depend only on a few constraints; - Processes are interdependent.
Primary effect	Reduced flow time	Uniform process output	High throughput
Secondary effects	- Less waste; - Increased throughput; - Less inventory; - Improved quality.	- Less variation; - Less inventory; - Improved quality.	- Less waste; - Less inventory; - Throughput cost accounting; - Improved quality.
Criticisms	- Statistical or system analysis not as valued; - Sensitive to demand fluctuations (low margin for error).	- System interactions not considered; - Processes improved independently; - Creates elite employees.	- Minimal worker input - Data analysis less valued; - Ignores parts of the organization to focus on constraints.

Six Sigma is a methodology that focuses on solving one problem at a time, independently from each other, in a structured, systematic and scientific manner. It is based on the belief that reducing variation in all processes will in turn improve the system output and ensure greater bottom-line results. The Theory of Constraints, on the other hand, takes a much broader view of the system and points out exactly where improvement efforts should be focused on. Managing the weak links in chain, and gradually eliminating them, is expected to lead to the maximization of profits. Finally, Lean is more than just a methodology for improving a production system; it *is* the production system, and an entire way of managing it, as well. Its aim is to provide the customer with perfect value through a perfect value creation process that has zero waste.

These very different descriptions mean that the three cannot be classified the same way. They can be labeled as CI methodologies, — or CI paradigms, since all of them are guided by an underlying philosophy — but this is certainly a vague way of putting it. And, as mentioned above, although Lean can be called a CI paradigm/methodology, it transcends this definition. Naturally, what all three have in common is the fact that they are claimed to improve operations and, consequently, lead to improved business results (i.e. higher profits) and happier customers.

There are some clear similarities between Lean and TOC. Both philosophies are concerned with improving flow and rely on pull systems. Lean employs kanban to signal the requirement of material from the preceding station, whereas in TOC, the flow of material from the first station to the last is controlled by DBR. Six Sigma looks at processes individually and therefore cares little about how they are chained together. Still, as Six Sigma improves processes, they often become faster (e.g. fewer defects means less scrap, rework and need for control), and consequently, flow is improved as well.

Both Lean and TOC also strive to reduce inventory, with some differences. Lean aims to have no inventory, with the sole exception of needed buffers to avoid mura. TOC tries to eliminate inventory at non-constraints, which is considered waste, but inventory in front of constraints is considered necessary to maintain an even flow and reduce dependency of the constraint. Six Sigma on the other hand can be used, for instance, to reduce the downtime of a given a process, which will prevent WIP from accumulating in front of it.

TOC does not use as many tools as Lean does, and is probably not as elaborate a system. This is easily understandable, given that TOC is fairly recent (1980's), while the original Lean system, the TPS, has been under development at Toyota since the 1940's. However, this does not mean that Lean tools cannot be used in a TOC organization, and vice-versa.

There are several other differences between Lean and TOC. In Lean, lines should be balanced, meaning that the output of every resource should be the same, while in TOC it is acceptable to have different output capability between resources (Josefsson, n.d.), so that there is only one constraint to manage. Some authors state that the size of process batches and transfer batches is usually the same in Lean, while TOC permits different batch sizes, however, other authors dispute this opinion. Another pointed difference is the fact that TOC is considered more tolerant of demand variability, while Lean supposedly performs better in repetitive production environment with less variability in demand (Josefsson, n.d.).

However, Lean and TOC's biggest difference regarding their continuous improvement natures has to do with what they focus on. Both methodologies take the whole system into account. But one of the underlying beliefs of Lean is that it is more important to make many small improvements along the entire chain to achieve perfect flow, rather than focus on a particular link in the chain with a view to improve the entire system. This is where TOC contrasts with Lean, as its basic assumption is that the overall throughput of the entire system depends on a few key links, i.e. the constraints. Therefore, TOC centers its improvement efforts on the constraints and subordinates everything else to them, in order to increase throughput. In other words, for TOC the only result that matters is the profit of the entire system, so it will mainly tackle the problems of the processes which affect the system the most, while Lean and its kaizen culture are concerned with improving every process every time an improvement opportunity arises.

The studies presented by some authors comparing the two methodologies claim that TOC provides the highest output and higher performance than Lean, while other authors claim it is Lean that provide the best possible results (Josefsson, n.d.). Perhaps more important is the fact that a good implementation of either methodology will certainly be more successful than a poor implementation of any methodology (Miltenburg, 1997).

Six Sigma is quite different from the other two, in that it does not take the overall system into account, nor the interdependencies between processes. One downside of this is that although a process may be improved after a Six Sigma project, unexpected consequences can happen to other processes further downstream. Another downside is that even if a process is greatly improved, it does not necessarily mean that there will be a significant improvement of the system's output. If that is the case, then the project will have added no value for the customer and will only have wasted precious resources. This is why project selection is an important part of Six Sigma. Tools such as the Pareto chart may be used to determine which project is the most immediately relevant for the organization. For example, whichever process is causing the most defects might be the most likely target of the next improvement project. Nevertheless, there is a greater chance of maximizing the impact of the project if project selection is guided by a methodology such as Lean or TOC.

Still, Six Sigma remains a very effective methodology. The reason for this is that what it lacks in strategy it makes up for in structure and rigor. Unlike previous improvement programs such as TQM, the DMAIC framework seamlessly integrates the vast set of tools developed over the years by the quality gurus and provides a systematic way to improve processes, allowing for little deviation from the project goals. Its dependence on data collection and analysis guarantees that the decision-making process is as objective and scientific as possible. Likewise, the infrastructure of people that is created within the organization not only trains experts in Six Sigma and the statistical tools it uses, it also lets each employee know what role they have to play in improvement projects.

But interestingly, it is not just Six Sigma that causes a cultural change within the organization. So do the other two philosophies. In fact, more than being a natural side effect of a well-implemented methodology, cultural change is a requirement for it to be successful. The kaizen culture characteristic of Japanese Lean organizations cannot be created overnight in a western organization. It is a gradual process that demands a great effort on the part of management to create the habits and values of an organizational culture of continuous improvement that all employees share. But only by going through this process can top management expect every employee to be concerned with improving every single element of production all the time.

TOC, on the other hand, also requires that employees understand the principles of constraints management. If they are not explained that TOC cares little about local efficiencies and, therefore, it is acceptable that some resources are idle for some of the time, then employees may unnecessarily worry about their jobs and have their workstation produce more than is required, which will harm the overall performance of the system. Naturally, regardless of whether the philosophy is TOC, Lean or Six Sigma, if an organization's culture is receptive of change it will be easier for employees to adapt to new situations, and thus allow the methodology to take root and be successful. If, instead, there is a cultural resistance to change, it will be harder for the implementation of the methodology to turn out successful (Berry and Smith, 2005).

That also means that if the organization is already used to a particular way of doing things that is mirrored by a particular improvement methodology, then it is probably best to choose that methodology for implementation. For example, if an organization is already used to carrying out analytical studies and values data, charts and analysis, then Six Sigma might be the best option (Nave, 2002).

Although the three philosophies have many differences, they all essentially strive for the same goals and the primary results of one are generally echoed by the secondary results of the others. Evidently, none of the methodologies is perfect. Each has its particular advantages as well as disadvantages, each as its strengths and weaknesses. For that reason, there is no objective way of determining which is best or which is worse. It is the job of managers selecting an improvement methodology to choose the one best fits the organization.

Nevertheless, there may be an alternative. Because the benefits provided by Lean, Six Sigma and TOC (and other methodologies) are somewhat different, and considering that each one's weak points are covered by the strong points of one of the other two, the next logical step would be to integrate two or more methodologies into a single, hybrid methodology. It makes sense to expect that the fusing of tools and concepts will create synergies that amplify the potential benefits from the implementation of either methodology by itself. It was by following that line of thinking that Lean Six Sigma was born.

4.5. The State of the Art: Lean Six Sigma

Many enterprises around the world have seen their operations improve substantially after the implementation of Lean programs, while many others found their success after setting up a Six Sigma initiative. The two CI methodologies share some of the same historical roots and even a few of the same tools, but despite their similarities they are still quite different in nature. Both have shown to possess their own individual strong points, making it pointless to single out one approach as "better" than the other. Instead of choosing between Lean and Six Sigma, since the two are complementary in many respects, it made more sense to reap the benefits of both by integrating them into a single business improvement methodology: Lean Six Sigma (LSS).

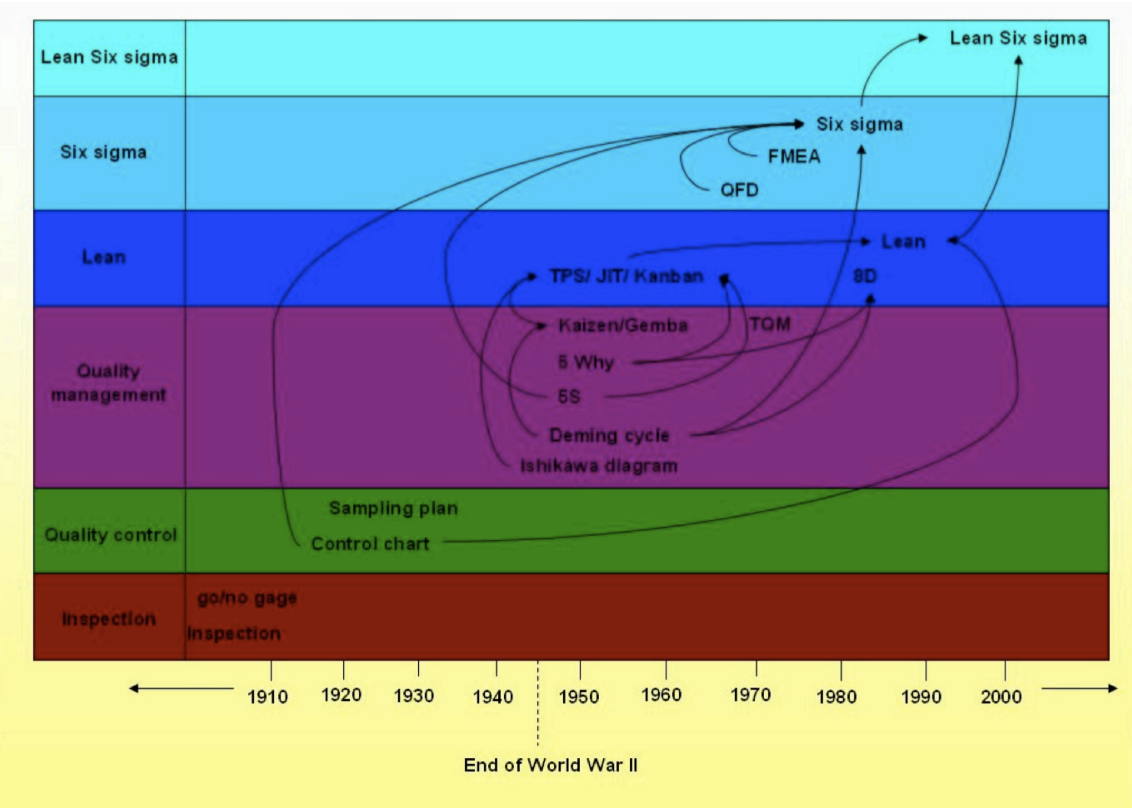

Fig. 1 - Evolution of CI Methodologies

Lean Six Sigma is the end result of the evolution (depicted in the figure above) of CI methodologies and techniques over the course of decades. Michael George was the first to put forward the concepts in 2002, claiming that the fusion of the two methodologies was a necessity, given that "Lean cannot bring a process under statistical control" and that "Six Sigma alone cannot dramatically improve process speed or reduce invested capital". Lean's effectiveness is particularly shown when dealing with the flow of information and materials, while Six Sigma's effectiveness is evident when addressing poorly performing value adding transformations (Snee, 2010). However, despite either approach being effective by itself, organizations often find themselves stagnating after initial improvement and struggle to create the necessary culture of continuous improvement (Arnheiter and Maleyeff, 2005).

Lean can overcome this by integrating the use of targeted data to make decisions and adopting a more scientific attitude towards quality, while Six Sigma must take a wider view of the system, considering the effects of muda on the system as a whole (Pepper and Spedding, 2010). This means that one methodology can support the other and vice-versa. Six Sigma can support a Lean initiative by providing the tools and know-how to address specific problems that arise during its implementation (Wheat *et al.*, 2003). Lean, in turn, can help Six Sigma maintain sight of the customer, lest it turn into a mere cost-reduction exercise (Bendell, 2005).

On the other hand, combining Lean's focus on eliminating waste with Six Sigma's focus on reducing variation makes it possible to target virtually every type of opportunity for improvement within an organization. Because of the synergy that is created between the two (see table below), LSS has the potential to achieve much greater success than either Lean or Six Sigma by itself. This is why George described this hybrid methodology as one that "maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital" (George, 2002).

Table 3 - The Synergy of Six Sigma and Lean Production (source: Pyzdek, 2000)

Lean	Six Sigma
Establish a methodology for improvement	Policy deployment methodology
Focus on customer value stream	Customer requirements measurement, cross-functional management
Use a project-based implementation	Project management skills
Understand current conditions	Knowledge discovery
Collect product and production data	Data collection and analysis tools
Document current layout and flow	Process mapping and flowcharting
Time the process	Data collection tools and techniques, SPC
Calculate process capacity and Takt time	Data collection tools and techniques, SPC
Create standard work combination sheets	Process control planning
Evaluate the options	Cause-and-effect, FMEA
Plan new layouts	Team skills, project management
Test to confirm improvement	Statistical methods for valid comparison, SPC
Reduce cycle times, product defects, changeover time, equipment failures, etc	Seven management tools, seven quality control tools, design of experiments

According to Antony (2004), some of the potential benefits for the organization include improved cross-functional teamwork, increased employee morale, improved consistent level of service, effective management decisions, and many others. The table above (Pyzdek, 2000) shows some examples of the synergy between the two methodologies. Since both of them deal with the problem of muda, albeit in different ways, there is a natural overlap of some of the concepts and activities.

Many well-known companies in a great variety of industries have endeavored to implement LSS programs and have achieved sizable savings to their bottom-line, as well as happier customers. Examples include General Electric, Johnson & Johnson, Merck, Allied-Signal/Honeywell, Du Pont, Bank of America, etc (Snee and Hoerl, 2003). Their results only encourage more and more companies into starting their own LSS initiatives. And it is easy to understand why by taking a closer look at the reported numbers.

On average, Green Belt projects return over $US50 thousand each, while Black Belt projects show a return in excess of $US175 thousand (Harry, 1998). Generally, in just six to twelve months after implementation, the LSS program will have passed the break-even point and paid for itself. A large organization will enjoy a return of 1-2 percent of sales each year, while a small to medium size organization will see returns of 3-4 percent in the same period (Snee, 2004). That means a company with a 4% savings rate and $US1 billion in sales will get to keep an extra $US40 million in savings each year. On top of that, assuming improvements are sustained over time (a difficult but critical task), savings will accumulate from year to year, thus 2% in the first year will become 4% in the second year, and 6% in the third year, and so on (Snee, 2006).

Yet, savings are not the whole picture. Consistently satisfying the customers' needs and making them happier, by providing them with high standards of quality, lower prices and faster deliveries, will likely result in the conquering of new customers, which translates into increasing sales. So not only will the organization continuously generate new savings to the bottom-line, it may also experience top-line growth.

All current evidence seems to show that a properly deployed LSS program has the potential to greatly improve a company's operations, yielding extraordinary results and providing it with many other benefits. This is certainly why some authors claim that "today, Lean Six Sigma is the improvement approach of choice" (Snee, 2010).

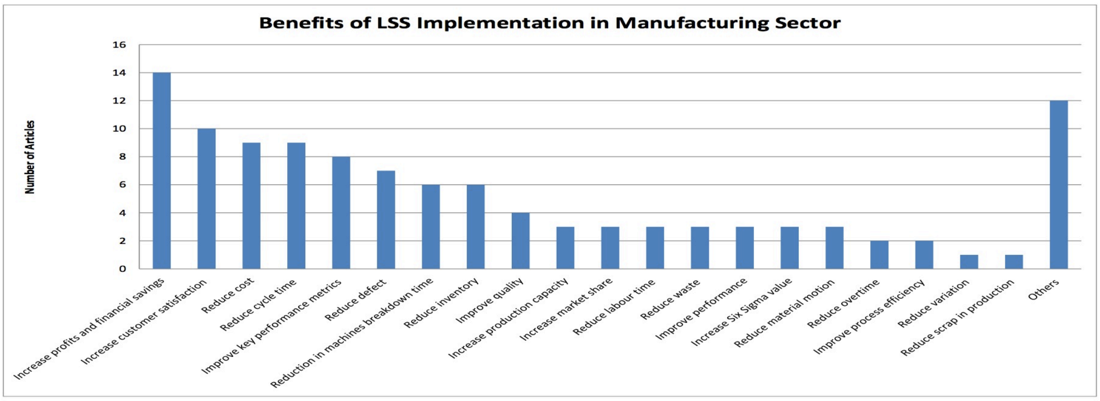

Fig. 2 - Benefits of LSS in the manufacturing sector (source: Albliwi and Antony, 2013)

4.5.1. The Challenge of Integrating Lean and Six Sigma

Although the concept of Lean Six Sigma is full of potential, in practice, integrating the two approaches has proven to be a hard task to accomplish. More often than not, rather than blending the two methodologies into one, they are implemented in isolation (Smith, 2003) — perhaps due to the fact that no guiding framework for integration has been agreed upon — which leads to the development of Lean and Six Sigma subcultures within the organization, usually causing a conflict of interests and a competition for resources (Bendell, 2006). Naturally, the common result of this is neither methodology being done effectively.

Additionally, for the fusion of Lean and Six Sigma to be truly effective, a state of equilibrium between the two must be reached, or in other words, neither approach should be predominant. Otherwise, one of two things can happen: if too much focus is placed on Lean, response to market variations may become less flexible, which will impact on value creation; and if the efforts are too focused on Six Sigma's objective of reducing variation and do so beyond the requirements of the customer while pursuing zero variation, then precious resources will go to waste. According to Pepper and Spedding (2008), "the balance lies in creating sufficient value from the customer's viewpoint, so that market share is maintained, while at the same time reducing variation to acceptable levels so as to lower costs incurred, without over-engineering the processes".

Partly because blending the two approaches is clearly not an easy task, several authors have criticized LSS over the years. One criticism is that the Lean and Six Sigma are joined without logical explanation or theoretical basis (Bendell, 2006), while another viewpoint is that the approaches are incompatible because workers on the ground floor cannot practice Six Sigma (Spector and West, 2006). Another author points that it is common for practitioners to occupy their time carrying out a large number of projects that return few results (Mika, 2006).

In order to avoid these often-mentioned pitfalls and limitations, a number of conceptual models have been proposed, aiming to obtain the maximum benefits from the integration of Lean and Six Sigma. Michael George has lead the development of Lean Six Sigma techniques, beginning with his book on the subject, published in 2002: *Lean Six Sigma: Combining Six Sigma with Lean Speed*. His approach, which is possibly the most widely adopted today, makes use of the DMAIC project methodology to guide the improvement effort, as well as the same martial-arts inspired, belt rank system. Each of DMAIC's phases is supported either by Lean or Six Sigma tools, or both, depending on the targeted problem.

There have been some efforts to create an industry-specific framework, such as the two successful case studies described by Smith (2003), or the work of Kumar *et al.* (2006) at an Indian SME, who integrated some lean techniques with the Six Sigma framework. In many ways, it makes sense that LSS is adjusted to the organization, blending the two methodologies in such a way that serves its specific needs and addresses the particular problems previously identified, rather than apply the same general framework in every organization. Of course, this approach requires a considerable amount of time (and other resources), which most organizations simply cannot spare.

Other works proposing original conceptual models include that of Hilton and Sohal (2012), or Pepper and Spedding's (2010) analysis of the evolution of Lean Six Sigma. Pepper and Spedding, for example, suggest that once Lean techniques are used to reduce complexity and interactions within the system, Lean will have identified improvement opportunities to be targeted by Six Sigma's more focused techniques, bringing the system closer to the desired lean state. They also argue that when creating a new and comprehensive framework for LSS, there are few key considerations: it needs to be strategic and process focused; it should be balanced between the two philosophies to harness the advantages of both; a balance between complexity and sustainability must be reached; and it should be structured around the type of problem experienced.

In Pepper and Spedding's proposed framework (2010), illustrated in the figure below, Lean would provide strategic direction and a foundation for improvement, guiding the general dynamics of the system by informing the current state of operations. Lean goes on to identify what they call "hot spots", i.e. key areas for improvement. Six Sigma then provides a focused, project based improvement methodology to target these hot spots and eventually drive the system towards its desire future state.

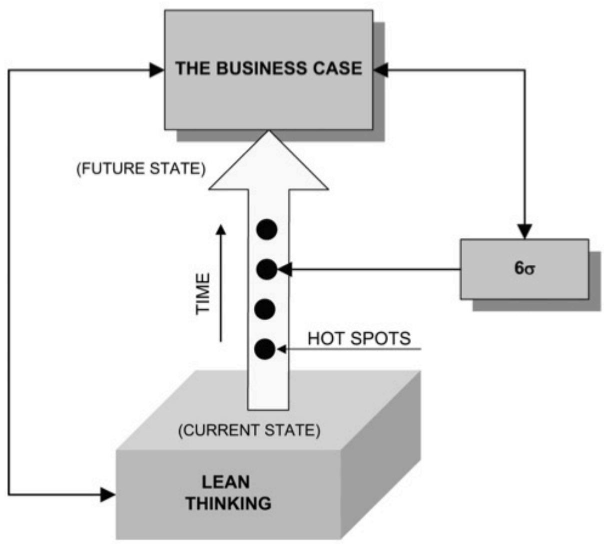

Fig. 3 - A conceptual model for Lean Six Sigma (source: Pepper and Spedding, 2010)

4.5.2. The Critical Factors of LSS

Since Lean Six Sigma is a fairly recent methodology, and although it builds on older improvement paradigms, the growing body of literature on the subject has often focused on identifying its critical success factors (CSF), as well as its critical failure factors (CFF), which in many cases are merely the former stated in the negative form. Despite the fact that many of these factors are naturally common to the two methodologies that LSS is based on, it remains a pressing issue for research. Organizations attempting to implement LSS programs are concerned with doing so in the most effective way, and thus want to make sure they are doing everything that is necessary to obtain solid, lasting results. They also wish to avoid making mistakes that would undermine the CI initiative.

Several authors, such as Coronado and Antony (2002), Snee (1999) or Henderson and Evans (2000) have proposed a number of CSF's. The following table presents a summary of the CSF's proposed by each of these authors, as presented in the work of Manville *et al.* (2012).

Table 4 - Summary of CSF's of LSS listed by authors (Source: Manville *et al.*, 2012)

Coronado and Antony (2002)	Snee (1999)	Henderson and Evans (2000)
Management involvement and commitment; Cultural change; Communication; Clear definition of strategy and goals of improvement efforts; Organization infrastructure; Training; Linking Six Sigma to business strategy; Linking Six Sigma to the customer; Linking Six Sigma to human resources; Linking Six Sigma to suppliers; Understanding its tools and techniques; Project management skills; Project prioritization and selection.	The right selection of people and projects; Communication of direction and potential benefits; Clearly allocated people, time, money and other resources; Recognition and reinforcement of desired improvement alternatives and behaviors.	Upper management support and involvement; Organizational infrastructure; Training; Tools; Links to human-based actions.

Albliwi and Antony (2013) carried out a systematic literature review on the topic of LSS. Their analysis of 21 case studies revealed over twenty distinct CSF's, the most common of which were training and education, followed by communication and top management commitment. The authors noted that CSF's varied from study to study, from company to company and from country to country. The ones noted as important in some studies were less so in others. The following graph presents those CSF's and how often each was mentioned in articles.

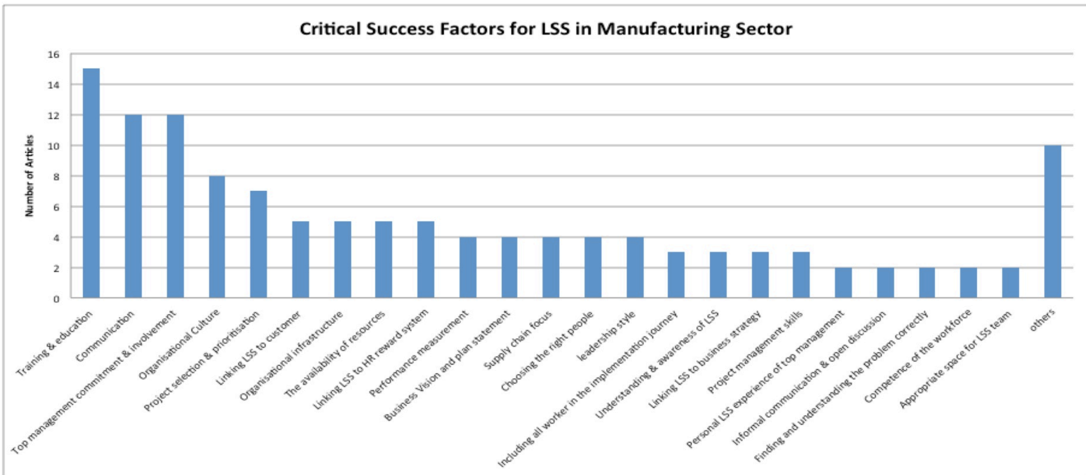

Fig. 4 - CSF's for LSS in the manufacturing sector (source: Albliwi and Antony, 2013)

In his later work, Snee (2010) added other CSF's such as: need to focus on improvement, not on training, which somewhat contrasts with the opinion shared by other authors that training is a CSF; top management involvement, a CSF that all authors agree on; building the supporting infrastructure, also agreed on by all authors; selecting the right projects; use of top talent to conduct improvement initiatives; planning for the sustainment of the improvements at the beginning of the initiative (Snee, 2010).

As for mistakes commonly made by organizations, Snee points out that the problems are found mainly in two areas, the CFF's of which are listed next. It should be noted that some of these (such as top talent not used) simply state the opposite of some of the aforementioned CSF's, and are therefore redundant. Problem areas and respective CFF's:

1. The management systems required administering and monitoring the improvement initiative - little leadership from top management including deployment plans — strategy, goals, etc.; poor or infrequent management reviews; top talent not used; poor support from finance, IT, HR, maintenance, and QC Lab.; focus is on training, not improvement; poor communication of initiative and progress; and lack of appropriate recognition and reward.

2. The selection and management of individual improvement projects - projects not tied to business goals and financial results; poorly defined project scope, metrics and goals; wrong people assigned to projects; project leaders and teams do not have sufficient time to work on projects; many projects lasting more than six months; little technical support from improvement master (Master Black Belt); large project teams (more than four to six persons per team); and infrequent team meetings.

4.5.3. Case Studies

The Lean Six Sigma literature is ripe with examples of its implementation in the most varied manufacturing industries and service organizations. Along with the traditional manufacturing plants, LSS initiatives as sprung in organizations in areas as diverse as healthcare, financial services, call centers, information technology, and many others. The two case studies that are presented in this section were chosen due to their well-documented nature and the fact they are generic enough to serve as examples for organizations developing work in the most diverse manufacturing industries.

Both cases regard SME's (Small and Medium Enterprises), one in the UK and one in India, and therefore are of interest to the vast majority of managers around the world, that usually lack the resources of larger enterprises for pursuing quality improvement initiatives. Nonetheless, the examples described ahead are just as valid for large corporations as they are for SME's.

By analyzing the following success stories, managers can, hopefully, better understand the potential impact that such a methodology can have on their organizations.

Case study #1

Thomas *et al.* (2009) describe Company A (the company requested confidentiality) as a UK-based "market leader in the research, development, manufacture and service of specialist seating systems for the automotive and aerospace industries", which employs over 150 people and has an annual turnover of £15 million. Despite the growth continually experienced over the years, the increasing competition from low-labor cost countries raised the need for the company to become leaner and more responsive to customers if they wish to retain their position as serious competitors in the market.

The company's strategic response to the competition was to shift their portfolio to the higher value market sectors, which proved to be highly successful financially, but required major changes to their manufacturing strategy. Thus the decision was made to adopt the Lean Six Sigma concept, with the aim of tackling customer CTQ issues promptly lest customers become dissatisfied and look for other suppliers. The company went on to develop an integrated LSS methodology that would provide a structured approach to solving CTQ problems and, of course, enhanced customer satisfaction and internal financial benefits.

One of the particular projects undertaken concerned the foam manufactured for the seat bases and chair backs. Scrapping foam parts is both costly and time-consuming, taking between one to two hours before firmness can be assessed after manufacture. A Pareto analysis was undertaken, which identified low-foam firmness as the major CTQ problem.

The company's LSS approach follows the Six Sigma's DMAIC project methodology. During the Define stage, the engineering team in charge of the project identified the low firmness issue and moved on to take measurements of the foam deflection, which revealed a deflection of

12mm, much lower than the internal standard of 10mm, meaning it was a seriously low firmness value. The Measure phase tested ten randomly chosen foams by simulating the movement experienced under normal operating conditions and then measuring the deflection of the foam. Six out of ten chairs failed the test procedure, which was a confirmation that the fault identified is real.

The multidisciplinary team of engineers proceeded with the Analyze stage, by having a brainstorming session to come up with potential factors that could influence foam firmness integrity. The result was a case and effect diagram identifying 12 factors, which ranged from humidity levels to shot volume. A further assessment of those reduced them to five: chemical mix, mold elevation, chemical temperature, mold temperature and time in mold. Once the factors had been identified, it was time for the Improve stage. A DOE experiment was conducted to identify the key factors and the interactions between them. The final result showed which were the optimal operational factor settings to obtain the required quality. The final phase of Control saw verification tests being carried out on the new settings and samples of five foam units being taken from the production line every hour for ten consecutive hours. A process control chart confirmed that all foam samples passed the firmness test. Further product tracking showed that after the improvements were introduced there were no recorded instances of product failure. The project was considered a highly successful.

Lean methods were also applied in the plant. The 5s system was implemented to clean and standardize the methods of working and operating. This made the following process of VSM far easier to visualize and assess. The VSM identified a 12% value stream. The major non-value added activities included: transportation (23%), queuing (40%), trimming (15%), others (10%). There was a lack of pull on customer demand and the batch and queue methods contributed heavily to the transportation and queuing times. A series of simple yet effective cost reduction projects was undertaken in order to improve flow and work practices. The trimming section was moved to link up between the two foam-manufacturing machines, removing the need to operate on a batch and stack approach. Conveyor systems were synchronized between the foam machines and the trimming section to allow the foams to cool on the conveyor and removed the need for a separate section to cool the foams as a batch.

Despite the LSS initiative still being recent, several cost savings have been identified to date:

- Reject rate reduction of 5%, equivalent to a potential saving of £29,000. Before LSS, the cost of rejects was £69,000, and afterwards it is £36,000;

- Cell overall equipment effectiveness up from 34% to 55%;

- Increase in parts per hour of 31%. Before LSS, throughput was 15 parts per hour, and afterwards it is 22 parts per hour. This amounts to 2,800 additional parts per year;

- Energy usage reduction of 12% per year. From 23,000 to 21,500 KW/h;

- The Total Productive Maintenance program, associated with LSS, reduced equipment downtime from 5% to 2%. Before LSS the downtime was around 100 hours, and afterwards only 40 hours.

It should be noted that the achieved savings in excess of £35,000 were the result of an investment of less than £5,000 in experimental and project costs. The implementation of LSS also pushed the company into developing more advances statistical techniques and thus become more "technical" in their approach to problem solving. Perhaps more important is the fact that the application of LSS led to the development of a culture towards continuous improvement and the systematic implementation of the approach throughout the organization.

In the case of Company A, the implementation of LSS was quick to reach success, despite the fact that the integration of the two methodologies is not as complete as it could be. However, this only means that the full potential of the LSS initiative has not yet been realized, and since it is still in its early stages, the development of an integration model that fits the company's needs may drive LSS to reach greater heights of success.

Case study #2

The work of Kumar *et al.* (2006) relates and analyses the implementation of LSS in an Indian SME. The company, started in the late 1970's, employs around 150 people and is dedicated to designing and manufacturing various types of precision machined components using pressure and gravity die-casting processes. Around 250,000 units of die casting products are manufactured every year and sold mostly to ordinance factories, the automobile industry and textile machine manufacturers — the company's three main customers. In order to keep up with market demand, employees work three 8-hour shifts per day, six days a week.

The rise in market demand led management to focus its efforts on production in order to meet customer orders. Consequently, the quality of the product began to drop. There was an increase in WIP inventory, scrap and rework cost, and more defects in the final product, such as cracks, foliation, pinhole porosity, etc. This was reflected in the rising number of customer complaints from different parts of the country. Soon management began to realize the importance of removing operation inefficiencies and wastes from the organization and set for itself the goal of reducing defects, WIP inventory, scrap and rework cost.

Management subsequently formed a team to identify the root cause of the problems and the team would later make the choice of implementing LSS over other CI methods. LSS was thought to be the best-suited method for pursuing the multiple goals of eliminating defects and variation, and reducing inventory and overall system complexity. The rationale behind the choice was that the integration of two approaches eliminates the limitations of a single individual approach. A decision was made to use Lean to create a foundation that would allow the tools of Six Sigma to yield greater benefits and faster. A framework was then developed for the LSS implementation in the organization, in which Lean tools are used within Six Sigma's DMAIC problem-solving methodology.

The proposed framework was deployed to address the problems of the die-casting unit. In the Define stage, a cross-functional team consisting of operators, engineers from production, quality and marketing department, as well as senior managers, spent many hours observing the different processes in the shop floor and collecting data. Brainstorming sessions were conducted to identify CTQ's based on the voice of the customer, and it was made clear that most complaints related to crack propagation in automobile accessories. A current state map was developed to identify opportunities for improvement, showing everything from die casting to shipping. The state map clearly showed an unacceptably high defect rate. The objective then would be to identify the root cause of the issue and reduce product defects.

During the Measure phase, the team was divided into small groups to better monitor the defects occurring in each process of manufacturing the die-casting product. Data had already been collected over the previous two years, which had been useful for identifying the critical processes where maximum defects occurred. Further data collected over a period of six days confirmed the historic data: the vast majority of defects came from the die-casting machine, the de-burring operation, and the chamfering and threading operation. Following that, a number of studies were undertaken to identify sources of variation in the measurement system and make sure the measurements of the die-casting parameter values were accurate enough for corrective actions to be taken in time during the experimental procedure. A performance standard was also determined, based on customer requirements, the conclusion of which was that customers want a solid casting with measurable characteristics, such as its density. Increasing the casting density therefore became the team's ultimate goal.

Moving on to the Analyze stage, the team divided the six casting defects into two types: internal and surface defects. A Pareto chart analysis showed that internal defects amounted to 67% of total defects. This type of defects is the result of poor casting density. The team concluded that the density of casting was the most important CTQ characteristic. A cause and effect diagram was also drawn to better understand the process parameters affecting density. It was crucial to know which are the most important process parameters, so that they could be properly tuned to achieve the desired range of casting density.

In the Improve phase, a designed experiment was carried out to identify the optimal settings of the main process parameters — the ones that provided maximum casting density. Once the optimum settings were identified, it was decided to implement a 5S system and Total Productive Maintenance, to establish a clean environment in the shop floor and to reduce the idle time of both machine and employees, respectively. Lastly, a confirmatory test was executed to validate the optimal settings of process parameters that had been previously determined. These new settings ensured an increase in casting density above 12%. The value of casting density was observed for the next three days of production.

In the final stage of Control, the optimal settings of process parameters were standardized in order to sustain the improved results. Control charts are now plotted regularly to check that the desired specifications are being met, and a number of different sensors (pressure, temperature, position and velocity) are now used to accurately measure the values of process parameters. Additionally, mistake-proofing exercises were carried out to reduce the number of defects occurring in a process.

Management is also focusing on: checking defects at the preliminary design phase, FMEA and other types of data analysis to pinpoint potential problems, use of cross-functional teams to discuss manufacturing/design problems likely to cause mistakes/defects/failures, sharing of performance information with employees, training people regarding production and quality issues, as well as problem-solving and team building, use of control charts and graphs at each processing stage, motivating employees, as well as recognizing and rewarding their contributions.

The implementation of LSS at the company was considered a success. It helped reach improvements in a vast number of areas: reducing the machine downtime; establishing a standard housekeeping procedure; increasing the confidence level among employees, instigating a sense of ownership among employees for their work; enhancing overall equipment/process effectiveness; rectifying the customer complaints; reducing inventory: reducing machine set up time; reducing the number of accidents at the workplace.

These improvements generated significant savings for the organization: the decrease in downtime from 6% to 1% resulted in estimated savings of over $US40,000 per year; the reduction of WIP inventory by over 25% translated into savings of over $US33,000; standard housekeeping procedures significantly reduced the number of accidents, which in turn reduced the amount of compensation paid to injured employees in about $US20,000 on average per year. Even more impressive are the savings generated by LSS efforts, estimated around $US46,500 per year, thanks to the enormous reduction in defects at every stage of production. In total, the savings generated amounted to $US140,000.

However, the implementation of LSS was not without obstacles. Convincing top management of the need for a continuous improvement system was particularly hard, since they were convinced that investing in quality meant increasing the cost of production, when in fact it is the other way around. Top management was only sold on the idea after being shown examples of success stories at other Indian companies. On the other hand, the employees also gave signs of resistance to the new business strategies. They believed the changes could endanger job opportunities and poor performance could mean the loss of their jobs. Top management had to let them know their jobs were not in danger and they would be rewarded for better performance, which gradually boosted their confidence. Management itself also resisted to the implementation of the 5S system, which they thought would have no impact on performance. They had to be shown the savings that could be generated by reducing the idle time of both operators and machines and by avoiding accidents.

The LSS initiative essentially drove the organization towards the establishment of best practices. The reported numbers clearly show its resounding success: the casting density improved by over 12%, the generated savings total $US140,000 per year and the key performance metrics (such as process capability, first time yield, etc) have demonstrated a significant improvement. This success has also had the additional benefit of promoting a cultural change within the company, making employees more engaged with systematic, continuous improvement.

4.6. The Future of Continuous Improvement

As was made clear in earlier chapters, quality and continuous improvement have a long, rich history. In recent times, the most significant development was Lean Six Sigma, which apparently still has a long way to go to reach its full potential. It seems legitimate to ask what the future might hold for continuous improvement and to speculate on the subject, based on current knowledge.

It is safe to say that most if not all current methodologies, tools and techniques of continuous improvement were invented out of need. Hence it is only logical to assume that future CI concepts will also arise out of need. The greatest developments can be expected to emerge in times of economic crisis or of fierce rivalry between organizations. This may come from organizations in any industry and in any part of the world, and although it is makes more sense to expect larger enterprises to drive continuous improvement forward, it would be good to remember the example of Toyota, which was very far from being a big company in the 1940's after WWII.

The quick development of new technologies also has a certain part to play in the creation of new CI tools and techniques. On the other hand, technological advancements not only help further the techniques currently used, they also give rise to new needs, including in the field of CI. However, some of the most relevant concepts in continuous improvement, such as those present in Lean or in TOC, were the brainchildren of some of the most creative minds the industry has ever witnessed. It is in the hands of future engineers and managers to be as creative as Dr. Deming or Taiichi Ohno. In that sense, human creativity will always play a larger role than technology ever can.

It can also be observed that all current CI methodologies were built on existing knowledge and on the back of previous methodologies, despite the fact that they developed entirely new concepts. With that in mind it would not be inappropriate to view the evolution of continuous improvement as a stairway. Each step leads to the next one and the only way is up, but there is no way to reach the upper steps without first setting foot on the ones that precede it. Put another way, it stands to reason that whatever the next development in CI will be, it will rely on current knowledge.

The present-day trend in continuous improvement seems to be hybrid methodologies. Lean Six Sigma is the most well known hybrid, and as was mentioned in earlier chapters, it makes perfect sense to integrate Lean and Six Sigma in order to benefit from the strengths of both methodologies and thus achieve better results. But despite its popularity, LSS is far from being the only hybrid to have been proposed. Some authors have discussed the possibility of joining Lean with TOC (e.g. Dettmer, 2001; Srinivasan *et al.*, 2004), while others assessed the alternative of fusing TOC with Six Sigma (e.g. Ehie and Sheu, 2005; Husby, 2007; Jin *et al.*, 2009).

Either of those hybrids stands a good chance of being successful, but perhaps the most interesting hybrid alternative would be the integration of TOC, Lean and Six Sigma, or TLS for short. In such a methodology, TOC would essentially serve to provide a wider view of the system and its needs, and thus focus the efforts of Lean Six Sigma on the constraints that keep it from being more profitable. As of 2016, some authors have published books and articles on the subject (Jacob *et al.*, 2010, Sproull and Nelson, 2015) and the body of literature is slowly growing. Yet, the applicability of TLS in real world scenarios remains largely unknown.

The idea of having a super CI methodology with all the strengths of Lean, Six Sigma and TOC and virtually none of its weaknesses is certainly attractive for any organization. However, combining three paradigms as complex and distinct as these in an effective manner may be unrealistic. It may still take some time to assess its feasibility, but even if TLS is not feasible it may serve as a stepping-stone for other future methodologies. Whether or not it does, continuous improvement will continue to evolve, albeit at a slow pace.

V. The 10 Commandments of Continuous Improvement

Continuous improvement approaches vary greatly in both theory and practice, yet it is not difficult to draw the parallels between them. By studying its history and analyzing its current paradigms and methodologies, a few universal truths and principles begin to surface. An extensive research of the literature, regardless of which CI philosophy or method was scrutinized, revealed the same often repeated ideas, which are true for any organization planning to implement a CI initiative.

Some of these implicit rules or commandments, if they can be called that, are the product of experience, while others emerged through common sense, empirical observation and logical inference. The principles of continuous improvement proposed in this chapter here are this author's exclusive view on the subject, resulting from an extensive literary research of the history, paradigms and methodologies of continuous improvement. Since none of these are scientifically proven and have not been peer reviewed, they cannot be claimed as absolute truths, nor can it be claimed that there are no others beyond these. Nevertheless, these universal principles are sure to serve as powerful guidelines for any organization to enjoy successful continuous improvement of its operations and results.

1. You must continuously improve

The first commandment of CI is fairly obvious and should go without saying. It is only common sense that an organization that does not improve will eventually stagnate. Worse than that, in time, if processes remain stagnated for a long period of time, they will begin to deteriorate. Also, just because one organization foregoes continuous improvement, it does not mean other organizations will do the same. Managers can expect competing organizations to keep improving their operations, regardless of whether they are better or worse than the manager's own organization. A competing organization will surely attempt to surpass you in quality, speed of delivery, service and price, and if that organization is already doing better, they will still try to widen the gap.

If you do not improve, someone else will, and your organization will go under. If you are not trying to get better all the time, even if the organization survives, it will lose the race. Simply put, success directly depends on continuous improvement. There is no way around it, you must improve and you must do so continuously.

2. You must have a continuous improvement system

Improvements cannot be random, unmethodical and happen irregularly. In order for the organization to improve continuously, there must be some sort of system in place that guides the improvements. Using a few scattered tools around the organization is not enough. On the one hand, there should be criteria to decide what the improvement needs of the organization are and what exactly to improve next. On the other hand, there should be a structured process for improving and tools to support it. Put another way, continuous improvement will be more efficient if it has an underlying philosophy to govern it and a methodology to carry out improvements in an organized, objective and cyclical fashion.

In other words, improvements need to be organized and systematic and must follow some kind of logic so that they produce lasting effects.

3. You must develop your own continuous improvement system

This does not mean managers should ignore the existing CI paradigms and methodologies. On the contrary, a CI system must be based on current knowledge and it makes perfect sense to adopt a philosophy such as Lean or Six Sigma. However, each organization has a set of unique characteristics, needs and strategic goals, and the chosen approach should fit well with these. Of course, even if the approach is chosen carefully, it will still have to be adapted to the organization's reality.

Some methods or techniques will have to be changed, while others will be of little use. The understanding of the philosophy itself must be flexible enough to fit with the particular industry or production environments. Lean, for example, certainly cannot be implemented in a European food factory in the same way that the TPS is used to run Toyota's plants in Japan because the realities are substantially different.

Naturally, adapting a CI paradigm requires intimate knowledge of the organization. Managers must understand the production environment, the processes that take place and their employees. It is a long process, but once your own CI system settles in, improvement projects and the way they are executed will be adjusted to the organization's needs and its benefits will be maximized. Practitioners can keep developing their own production concepts, methods and techniques, and in time the CI system will be unique and may even be mimicked by other organizations.

4. You must be prepared for a long-term effort

No organization turns successful over night. Even if a CI program is the best possible for the company, it will still take some time before there is a significant impact on the bottom-line. So if an improvement initiative does not produce immediate results, it is no cause for despair. If at first a continuous improvement effort does not succeed, if it is taking too much time or if managers think that enough improvements have been made, there is nothing to be gained by giving up on it.

Results take time to appear and a much longer time to turn into tangible success. The fact that improvement must be continuous means there is no end in sight. Improving is a cyclical process that keeps repeating itself *ad aeternum*. It is a long-term effort that requires vision and persistence. Toyota's development of the TPS over the course of several decades is arguably the best example of this (Womack *et al.*, 1990). But there are many other authors who address this issue, such as in the work of Bessant *et al.* (1994). Once continuous improvement begins, it must never end.

5. You must have top management support

A continuous improvement initiative has no chance of being successful without top management support. This is mentioned countless times throughout the literature (Coronado and Antony, 2002; Snee, 2010; Henderson and Evans, 2000; etc.). It is a critical success factor of every improvement methodology. Top management must be aware of the importance of CI for the success of the organization. It must be willing to take action and support CI efforts even when they are not producing results. It must be willing to help when organizational culture is showing resistance to change. It must understand the long-term nature of CI and patient enough to wait for results.

Without top management support, the "abominable Ohno system", as it was called from the late 1940's to the late 1960's, would have been abandoned and would never have become the Toyota Production System. If Jack Welch, former CEO of General Electric, had not believed in the potential of Six Sigma and had not invested $US500 million in the first few years, it is likely the methodology would not be half as popular today (Harry and Schroeder, 2000). Top management alone has the power to set off continuous improvement in the organization and to keep it going until it begins to show signs of success.

6. You must create a culture of continuous improvement

This is a well-studied matter that has been extensively addressed throughout the literature. Continuous improvement must be well integrated in the organizational culture if its true potential is to be realized. Initially, most organizations are resistant to change because the previous way of doing things is still deeply rooted in its culture.

Employees must be told the reasons behind the changes and the benefits that continuous improvement can bring. They must be encouraged to participate and proactively contribute to improvement every day. If the workforce feels involved and empowered, the CI efforts are much more likely to succeed. The kaizen culture in Japan is surely the best example of this.

Evidently, creating such a culture takes patience, understanding and time, which is another reason why continuous improvement is a long-term effort.

Failing to create a culture that supports continuous improvement, its efforts will be undermined every step of the way and results, even when good, will always be poorer than they could be.

In this matter, Toyota has certainly set the example for every organization to follow: "Furthermore, all Toyota production divisions are making **improvements** to the TPS day and night to ensure its **continued** evolution" (Toyota Global Site[a]). The work of authors such as Mann (2003), Atkinson (2010) and many others also supports this notion.

7. You must improve everything

Managers should operate under the assumption that everything in the organization is improvable. Processes and products are the most recurrent targets for improvement. People, for instance, also need to be improved and it is critical to do so. Through employee training, organizations increase their human capital, which in the long term will pay off in productivity. Services the company provides, such as delivery or customer care, also need constant attention. The same attention must be given to physical infrastructures, equipment, materials, policies, relationships with suppliers, etc. In short, no aspect of the organization can be disregarded.

Needless to say, even if managers are willing to improve everything, the most pressing issues within an organization will have to take priority over others, but that does not mean managers should not strive to make the organization as efficient and productive as possible. An excellent example of this is that of Toyota, which not only strives for the improvement of everything within the corporation, but also goes beyond that by helping its business partners improve their operations, even loaning its experts in various fields to share know-how.

Womack *et al.* (1990) and Liker (2004), who studied Lean and the TPS in depth, mention frequently how Toyota leaves nothing to chance, encouraging its workers to improve every little thing even if it seems of no importance. Everything along the value chain, from suppliers to customers, is the focus of improvement.

8. You must have ambitious improvement goals

There is no such thing as improving "enough". Managers should always endeavor to improve more than they know it to be possible. In other words, the organization should aim higher than it can reach. By setting improvement goals that seem unattainable, employees are more easily encouraged to work their best to achieve them.

[a] http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/origin_of_the_toyota_production_system.html

To give an example, the success of Six Sigma at Motorola was partly due to the company's ambitious goals. Management had decided it was not enough to just get "better" and instead it was critical to promptly become excellent. Therefore, the company set itself the goal of improving all products by an order of magnitude (i.e. a factor of ten) within five years, which proved to be a motivating factor for employees (Klefsjö *et al.*, 2001).

One way to set the bar high enough is for the organization to focus on becoming better than both the competition and itself. So long as there is a competing company that is better in anyway, the goal should be to improve your organization until it surpasses them in every aspect. On the other hand, regardless of whether or not you are already ahead of the competition, your organization should always have the internal goal of transcending itself. In simple terms, make yourself better than you are. This will ensure improvement is continuous, that more is achieved with each improvement project and that workers have permanent motivation.

9. You must beware of inertia

This caveat for CI practitioners is taken from Eliyahu Goldratt's Theory of Constraints, however, it has been stated often, albeit in other words, in the literature of other methodologies. It is meant to remind us that there is always more to improve. After undergoing a great number of improvements and having the organization running at its highest efficiency level ever, it is a common mistake to let inertia take over and stop improving.

It is easy to give in to complacency or simply fail to identify other needed improvements, and this is why CI practitioners should always be moving from one project to the next without interruptions. Perpetual movement can be seen as the key to avoiding this. The physics concepts of inertia and momentum tell us that the heavier the object and the faster it is moving, the harder it is to stop, and the same holds true for CI initiatives. In other words, continuous improvement must never be allowed to slow down.

10. You must improve the way you improve

Continuous improvement is not just a meta-process in the sense that it transforms other processes. It is also a meta-process because from time to time it must also be aimed at itself. This should happen proactively. Burton's work (2014) focuses directly on this issue. As he states, you need to "improve how you improve".

The CI system of an organization should never be static. And neither should the philosophy and methodologies that support it. As industries permanently evolve, so do CI paradigms and methodologies. Managers should keep learning everything they can about continuous improvement and always be aware of emerging methods, techniques or management concepts. They must also proactively use their own means to try to better the ways in which the organization seeks improvement. In simpler terms, one must improve the process of continuous improvement.

Just as Snee observed that Lean Six Sigma "needs to be continually challenged and enhanced to make the approach better" (Snee, 2010), the same can be said of any and all subjects related to continuous improvement. This very list of commandments should continuously be revised and updated as new knowledge becomes available. Ten commandments could easily turn into twenty or thirty.

More specific principles could have been included on this list, such as basing all decisions on data or always focusing on the causes instead of firefighting. However, it seems wiser to rely only on general principles that can serve as solid foundations for implementing whichever CI philosophy an organization chooses, in whichever industry it is inserted in.

It should be noted that this list of rules is in no way final. These were chosen for their degree of importance and unambiguity, but are certainly not the only ones. Every researcher and practitioner of CI methodologies has a unique perspective on the subject, therefore revisions to these ten commandments are to be expected and welcomed.

VI. Conclusions

This study was focused on understanding the past, present and future of continuous improvement. The importance of CI systems for present-day organizations is undeniable, whether they are manufacturing or service organizations. Adopting and developing a continuous improvement system is more than just a requirement for potential success, it is a critical factor for survival. It is the job of managers to learn about the current paradigms and methodologies to find the one that best suits the organization and then strive to improve.

6.1. General Conclusions

The history of continuous improvement is a long and rich one. It is interlaced with the history of quality and can be traced back to the dawn of civilization, although most major developments and leaps forward only came about after the industrial revolution. Throughout the twentieth century, a vast number of methods, techniques and philosophical concepts that would come to shape today's CI paradigms, were developed all around the world by management gurus, often in the service of major corporations. Continuous improvement often developed out of necessity and would indeed prove to be part of the solution in times of economic crisis. Corporations such as Toyota rose from near bankruptcy to the top on the back of their CI efforts, effectively certifying its importance for organizations.

Lean is a philosophy based on the TPS, a whole a different way of producing compared to the previous methods of mass production. It is aimed at removing all waste in order to provide perfect value to its customers. It relies heavily on a company culture of continuous improvement, kaizen, which has been essential to its success.

Six Sigma is a methodology developed at Motorola and General Electric that provides a structured process for continuous improvement and the infrastructure of people necessary to do it. It is based on the collection and analysis of data and makes coherent use of statistical tools and techniques that were previously used with little method, and therefore ineffectively. Due to its systematic and structured approach, Six Sigma succeeded where TQM had previously come short.

The Theory of Constraints is an improvement paradigm developed by Eliyahu Goldratt. It focuses on finding the weak links in the system that are holding it back from achieving higher profits and managing them for better results. Its concern with the overall throughput of the system makes it effective at reaching significant improvements in short periods.

A comparison of these paradigms and methodologies shows there are noticeable similarities and differences between them. They all have strengths and weaknesses, advantages and disadvantages, therefore neither of them stands out as being the "best". Each organization must assess them to find which of them better suits its strategy, characteristics and needs.

It is generally agreed that if the organization chooses wisely and makes a proper effort to implement a methodology that suits its long-term vision and needs, the impact on results will be significant. Savings will be added to the bottom-line and customers will be happier, which in turn could increase sales (top-line growth).

Ideally, a continuous improvement system would have all the strengths and none of the weaknesses of all the methodologies that were analyzed, which is why hybrid methodologies began to emerge. The idea of integrating two or more methodologies and thus reap maximum benefits is an attractive one. This is how Lean Six Sigma came to be.

Lean Six Sigma, as the name suggests, attempts to integrate Lean and Six Sigma into a single methodology in order to enjoy the strengths of both. The two methodologies are said to complement each other, however no consensus has been reached on an adequate integration model. Most of today's implementations of LSS consist on the parallel application of the two methodologies and therefore do not constitute a true integration. This leads to the author's belief that LSS is yet to reach its full potential. Yet, in the organizations that made a serious effort to implement LSS effectively, it caused a significant impact in bottom-line results and customer satisfaction. It will likely produce similar results in other organizations so long as it is carefully implemented.

LSS is not however the only hybrid methodology. The combination of Lean and TOC has been studied and tried before, and the fusing of TOC and Six Sigma has also been suggested. Researchers are now proposing the integration of Lean, Six Sigma and the Theory of Constraints, which is yet to be proven as a feasible and effective approach. The trend of hybrid methodologies is certainly bound to continue in the future.

Regardless of which philosophy or methodology a company chooses to implement or elaborate on, a certain set of principles can be defined based on experience, observation and logic, which hold true for any organization employing any paradigm. They constitute universal rules that if followed ensure a higher probability of a successful implementation of a CI program.

These commandments can never be reminded too often: 1. You must continuously improve; 2. You must have a continuous improvement system; 3. You must develop your own continuous improvement system; 4. You must be prepared for a long-term effort; 5. You must have top management support; 6. You must create a culture of continuous improvement; 7. You must improve everything; 8. You must have ambitious improvement goals; 9. You must beware of inertia; 10. You must improve the way you improve.

6.3. Limitations and Future Research

This being an academic work that relies on literature review, albeit a very extensive one, leaves room open for a field study with particular regard to the commandments for successful implementation of continuous improvement systems. The commandments presented are based upon three factors: an analysis of the history of CI, an analysis of the most widely adopted paradigms and methodologies and an analysis of case studies in the literature of both successful and failed implementations in the industry. However, the case studies in the literature were not written with these commandments in mind.

There was no opportunity for a field study in organizations where CI systems have been implemented, which would serve to confirm if the commandments were followed in successful implementations and disregarded in failed ones. A case study with that purpose could potentially support the theoretical findings of this dissertation with practical results. It would serve to identify which commandments are most commonly followed and which are more important for success in the view of practitioners, and could in theory reveal the correlation between the importance of each commandment and the degree of success of CI systems. Naturally, this can be the subject of a future study to further understand these commandments and how they interrelate.

On a different note, the paradigms and methodologies chosen for analysis in this study are at present the most popular and most researched, and their worth has been proven. However, there is a vast amount of literature on the subject of continuous improvement and much has been written over the years about many other methodologies and management fads. Researching other lesser-known methodologies as well as those that proved to have little effectiveness and comparing them to Lean, Six Sigma, TOC and Lean Six Sigma would make for an interesting and valuable article for the study of continuous improvement. However, there is little information on some of the lesser-known methodologies. The literature on the subject is scarce and hard to find. To focus on it would require a longer period of time that would distract from the main subject.

The emerging hybrid methodologies would also make an interesting topic of research. In particular, there is still much to investigate on the integration of TOC, Lean and Six Sigma. It is a concept that has the potential to turn out to be very appealing to organizations in the near future, yet few authors have addressed it.

VII. Bibliography

7.1. Cited References

Albliwi, S., Antony, J. (2013), "Implementation of a Lean Six Sigma approach in the manufacturing sector: a systematic literature review", *Proceedings of the 11th International Conference on Manufacturing Research*.

Andersson, R. & Eriksson, H., Torstensson,H. (2006), "Similarities and differences between TQM, six sigma and lean", *The TQM Magazine*, Vol. 18 No. 3, pp. 282-296.

Antony, J. (2004), "Six Sigma in the UK service organisations: results from a pilot study", *Managerial Auditing Journal*, Vol. 19 No. 8, pp. 1006-1013.

Anvari, A., Ismail, Y., Hojjati, S.M.H. (2011), "A Study on Total Quality Management and Lean Manufacturing: Through Lean Thinking Approach", *World Applied Sciences Journal*, Vol. 12 No. 9, pp. 1585-1596.

Arnheiter, E.D., Maleyeff, J. (2005), "The integration of lean management and six sigma", *The TQM Magazine*, Vol. 17 No. 1, pp. 5-18.

Atkinson, P. (2010), "'Lean' is a Cultural issue", *Management Services*.

Balderstone, S.J., Mabin, V.J., (date unknown), *A Review of Goldratt's Theory of Constraints (TOC) – lessons from the international literature*, Victoria University of Wellington, New Zealand.

Bendell, T. (2005), "Structuring business process improvement methodologies", *TQM Magazine*, Vol. 16 Nos. 8/9, pp. 969-78.

Bendell, T. (2006), "A review and comparison of six sigma and the lean organisations", *The TQM Magazine*, Vol. 18 No. 3, pp. 255-62.

Berry, R., Smith, L.B., (2005), "Conceptual foundations for the Theory of Constraints", *Human Systems Management*, No. 24, pp. 83-94, IOS Press.

Bessant, J., Caffyn, S., Gilbert, J., Harding, R., Webb, S. (1994), "Rediscovering continuous improvement, "Technovation", Vol. 14 No. 1, pp. 17-29.

Bhuiyan, N., Baghel, A. (2005), "An overview of continuous improvement: from the past to the present", *Management Decision*, Vol. 43, No. 5, pp. 761-771.

Boer, H., Berger, A., Champna, R., Gertsen, F. (2000), "CI Changes: From Suggestion Box to Organisational Learning", *Continuous Improvement in Europe and Australia*, Ashgate, Aldershot.

Brook, Q. (2006), *Six Sigma and Minitab - A Complete Toolbox Guide for all Six Sigma Practitioners*, QSB Consulting Ltd.

Burton, T.T. (2014), *A history of lean and continuous improvement*, The Center for Excellence in Operations, Inc.

Cameron, R., Neal, L. (2003). *A Concise Economic History of the World: From Paleolithic Times to the Present*. Oxford University Press. p. 161.

Chiarini, A. (2012), *From Total Quality Control to Lean Six Sigma - Evolution of the Most Important Management Systems for the Excellence*, Springer.

Coronado, R., Antony, J. (2002), "Critical success factors for the successful implementation of Six Sigma projects in organisations", *The TQM Magazine*, Vol. 14 No. 2, pp. 92-99.

Deming, W.E. (1993), *The New Economics for Industry, Government, and Education*. MIT Press, Boston, MA.

Dettmer, H.W. (2001), *Beyond Lean Manufacturing: Combining Lean and the Theory of Constraints for higher performance*, Port Angeles, US.

Ehie, I., Sheu, J. (2005), "Integrating six sigma and theory of constraints for continuous improvement: a case study", *Journal of Manufacturing Technology Management*, Vol. 16, No. 5, pp. 542–553.

Fryer, K.J., Antony, J., Douglas, A. (2007), "Critical success factors of continuous improvement in the public sector", The TQM Magazine, Vol. 19 No. 5, pp. 497-517.

Gack, G.A. (2007) *Best Practices Fusion: Lean Six Sigma and ITIL*, Process-Fusion.net, LLC.

George, M. (2002), *Lean Six Sigma: Combining Six Sigma with Lean Speed*, McGraw-Hill.

George, M., Rowlands, D., Kastle, B. (2004), *What is Lean Six Sigma?*, McGraw-Hill.

Graham, L.D. (1998), *Managing On Her Own: Dr. Lillian Gilbreth and Women's Work in the Interwar Era*, Engineering & Management Press, Norcross, GA, USA.

Goldratt, E.M., Cox, J. (1984), *The Goal*, Third Edition, Gower Publishing Company.

Goldratt, E.M. (2008), "Standing On The Shoulders Of Giants: Production Concepts versus Production Applications - The Hitachi Tool Engineering Example", *The Goal*, Gower Publishing Company.

Harry, M.J. (1998), *Six Sigma: a breakthrough strategy for profitability*, Quality Progress, May.

Harry, M., Schroeder (2000), *Six Sigma - The Breakthrough Management Strategy Revolutionizing The World's Top Corporations*, Random House, Inc.

Henderson, K.M., Evans, J.R. (2000), "Successful implementation of Six Sigma: benchmarking general electric company", *Benchmarking: An International Journal*, Vol. 7 No. 4, pp. 260-81.

Hilton, R.J., Sohal,A. (2012), "A conceptual model for the successful deployment of Lean Six Sigma", *International Journal of Quality & Reliability Management*, Vol. 29 No. 1, pp. 54-70.

Husby, P. (2007), "Competition or Complement: Six Sigma and TOC", *Material Handling Management*, pp. 51–55.

Imai, M. (1986), *Kaizen: The Key to Japan's Competitive Success*, Random House, New York, N.Y.

Jacob, D., Bergland, S., Cox, J. (2010), *Velocity: Combining Lean, Six Sigma and the Theory Of Constraints to Achieve Breakthrough Performance*, Free Press.

Jin, K., Hyder, A.R., Eikassabgi, Y., Zhou, H., Herrera, A. (2009), "Integrating the Theory of Constraints and Six Sigma in Manufacturing Process Improvement", *Proceedings of world academy of science, engineering and technology*, Vol. 37.

Josefsson, J. (no date), *Comparing JIT and TOC: a comparison regarding methodology and performance*.

Juergensen, T. (2000), *Continuous Improvement: Mindsets, Capability, Process, Tools and Results*, The Juergensen Consulting Group, Inc., Indianapolis, IN.

Juran. J.M. (1995), *A History of Managing for Quality: The Evolution, Trends, and future Directions of Managing for Quality*, First Edition, Irwin Professional Publishing.

Khan, I. (2011), "Kaizen: The Japanese Strategy for Continuous Improvement", *VSRD International Journal of Business & Management Research*, Vol. 1 No. 3, pp. 177-184.

Klefsjö, B., Wiklund, H., Edgeman,R. (2001), "Six Sigma as a methodology for total quality management", *Measuring Business Excellence*, Vol. 5 No. 1, pp. 31-35

Kuhn, T.S. (1996), *The structure of scientific revolutions*, University of Chicago Press, Chicago, IL.

Kumar, M., Antony, J., Singh, R.K., Tiwari, M.K., Perry, D. (2006), "Implementing the lean sigma framework in an Indian SME: a case study", *Production Planning & Control*, Vol. 17 No. 4, pp. 407-23.

Liker, J.K. (2004), *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill.

Linderman, K., Schroeder, R., Zaheer,S., Choo, A. (2003), "Six Sigma: A goal-theoretic perspective", *Journal of Operations Management*, Vol. 21, No. 2, pp. 193-203.

Mabin, V.J., Balderstone, S.J. (1999), *The World of the Theory of Constraints: A Review of the International Literature*, St. Lucie Press.

Mann, D. (2003), "The Case for Lean Culture", *Target Volume*, Vol. 19 No. 4, pp. 20-29.

Manville, G., Greatbanks, R., Krishnasamy, R, Parker, D.W. (2012), "Critical success factors for Lean Six Sigma programmes: a view from middle management", *International Journal of Quality & Reliability Management*, Vol. 29 No.1, pp. 7-20.

Margavio, G.W., Margavio, T.M., Fink, R.I. (1995), "Managing the cost of quality in the era of continuous improvement", *CMA Magazine*, Vol. 69 No.11, pp. 29-31.

Martichenko, R. (2004), "Continuous improvement what's the problem", *Logistics Quarterly*, Vol. 10 No. 4.

Martinez-Lorente, A.R., Dewhurst, F., Dale, B.G. (1998), "Total Quality Management: Origins and evolution of the term", The TQM Magazine, Vol. 10 No. 5, pp. 378-386.

Mika, G. (2006), "Six Sigma isn't lean", *Manufacturing Engineering*, Vol. 137 No. 1.

Miltenburg, J. (1997), "Comparing JIT, MRP and TOC, and embedding TOC into MRP", *International Journal of Production Research*, Vol. 35, No. 4, pp. 1147-1169.

Mingers, J., Brocklesby (1997), "Multimethodology: Towards a framework for mixing methodologies", *Omega*, Vol. 25, pp. 489-509.

Näslund, D. (2008), "Lean, Six Sigma and Lean Sigma: fads or real process improvement methods?", *Business Process Management*, Vol. 14, 269-287.

Nave, D. (2002), "How to compare Six Sigma, Lean and the Theory of Constraints: a framework for choosing what is best for your organization", *Quality Progress*, Vol. 35 No. 3, pp. 73-78.

Ohno, T. (1988), *Workplace Management*. Translated by Jon Miller, Gemba Press.

Ohno, T., Mito, S. (1988), *Just-In-Time For Today and Tomorrow*, Productivity Press.

Pacheco, D.A.J. (2014), "Theory of Constraints and Six Sigma: investigating differences and similarities for continuous improvement", *Independent Journal of Management & Production*, Vol. 5 No. 2, pp. 331-343.

Pande, P.S., Neuman, R.P., Canagh, R.R. (2000), *The Six Sigma Way*, McGraw-Hill, New York, NY.

Pepper, M.P.J., Spedding, T.A. (2010), "The evolution of lean Six Sigma", *International Journal of Quality & Reliability Management*, Vol. 27 No. 2, pp. 138-155.

Pyzdek, T. (2000), *Six Sigma and lean production*, Quality Digest, January.

Shewhart, W.A. (1931), *Economic control of quality of manufactured product*. New York City: D. Van Nostrand Company, Inc.

Shingo, S., (1985), *A revolution in manufacturing: The SMED system*, Productivity Press.

Smith, B. (2003), "Lean and Six Sigma – a one-two punch", *Quality Progress*, Vol. 36 No. 4, pp. 37-41.

Snee, R.D. (1999), "Impact of Six Sigma: today and in the future", paper presented at the 1999 ASA Quality and Productivity Research Conference, Schenectady, NY, 21 May.

Snee, R.D. (2004), "Can Six Sigma boost your company's growth?", *Harvard Management Update*, June, pp. 2-4.

Snee, R.D. (2006), "The hard part: holding gains in improvement: sustaining the gains begins when the improvement initiative is launched not after the improvements are achieved", *Quality Progress*, September, pp. 52-56.

Snee, R.D. (2010), "Lean Six Sigma - getting better all the time", *International Journal of Lean Six Sigma*, Vol. 1 No. 1, pp. 9-29.

Snee, R.D., HOERL, R.W. (2003), *Leading Six Sigma – A Step-by-step Guide Based on Experience with GE and Other Six Sigma Companies*, Financial Times/Prentice-Hall, New York, NY.

Sokovic, M., Pavletic, D., Pipan, K.K. (2010), "Quality Improvement Methodologies - PDCA Cycle, RADAR Matrix, DMAIC and DFSS", *Journal of Achievements in Material and Manufacturing Engineering*, Vol. 43 Issue 1, pp. 476-483.

Spector, R.E. (2006), "How Constraints Management enhances Lean and Six Sigma", *Supply Chain Management Review*.

Spector, R., West, M. (2006), "The art of lean program management", *Supply Chain Management Review*.

Sproull, B., Nelson, B. (2015), *Epiphanized: A Novel on Unifying Theory of Constraints, Lean, and Six Sigma*, Second Edition, Productivity Press.

Srinivasan, M.M., Jones, D.T., Roos, D. (2004), "Applying theory of constraints principles and lean thinking at the marine corps maintenance center", *Defense Acquisition Review Journal*, pp. 134-135.

Taylor, F.W. (1911), *The Principles of Scientific Management*, Harper & Brothers, New York, NY, US and London, UK.

Thomas, A., Barton, R., Chuke-Okafor, C. (2009), "Applying lean six sigma in a small engineering company - a model for change", *Journal of Manufacturing Technology Management*, Vol. 20 No.1, pp. 113-129.

Thomson, R. (1989), *The Path to Mechanized Shoe Production in the United States*, The University of North Carolina Press, Chapel Hill and London.

Wheat, B., Mills, C., Carnell, M. (2003), *Leaning into Six Sigma: A Parable of the Journey to Six Sigma and a Lean Enterprise*, McGraw-Hill, New York, NY.

Womack, J.P., Jones, D.T., Roos, D. (1990), *The machine that changed the world*, Simon & Schuster UK Ltd.

Womack, J.P., Jones, D.T. (1996), *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Simon & Schuster UK Ltd.

Woodham, J. (1997), *Twentieth-Century Design*, Oxford University Press, New York, NY, USA and London, UK.

7.2. Cited Websites

"Continual Improvement - Chartered Quality Institute", *http://www.thecqi.org/Knowledge-Hub/Resources/Factsheets/Continual-improvement/* - Retrieved on 5 June 2016.

"Continuous Improvement Model - Learning Resources | ASQ", *http://asq.org/learn-about-quality/continuous-improvement/overview/overview.html* - Retrieved on 5 June 2016.

"Six Sigma Interview with Jack Welch", *http://www.youtube.com/watch?v=aNMULFcLuIM* - Retrieved on 5 June 2016.

"Toyota Global Site | The origin of the Toyota Production System", *http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/origin_of_the_toyota_production_system.html* - Retrieved on 5 June 2016.

7.3. Other References

Angell, L.C., Chandra, M. J. (2001), "Performance implications of investments in continuous quality improvement", *International Journal of Operations & Production Management*, Vol. 21 No. 1/2, pp. 108-125.

Caffyn, S. (1999), "Development of a continuous improvement self-assessment tool", *International Journal of Operations and Production Management*, Vol. 19 No. 11, pp. 1138-1153.

Deming, W. E. (1982), *Out of the crisis*, MIT Press, Cambridge, MA.

Dinero, D. (2005), T*raining Within Industry: The Foundation of Lean*, Productivity Press, Portland, OR.

Färe, R., Grosskopf, S., Lovell, C.A.K. (1986), "Scale economies and duality", *Zeitschrift für Nationalökonomie*, 46:2, pp. 175–182.

Gupta, M., Snyder, D. (2009), "Comparing TOC with MRP and JIT: a literature review", *International Journal of Production Research*, Vol. 47 No. 13, pp. 3705-3739.

Hounshell, D.A. (1984), *From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States*, Johns Hopkins University Press, Baltimore, Maryland.

Houston, A., Dockstader, S.L. (1997), *Total Quality Leadership: A Primer*, United States Navy, pp. 10-11.

Ishikawa, K. (1985), *What is Total Quality Control? The Japanese Way*, Prentice Hall.

Juran, J.M. (1951), *Quality Control Handbook*, McGraw-Hill, New York, NY.

Juran, J.M. (2004), *Architect of Quality: The Autobiography of Dr. Joseph M. Juran*, McGraw-Hill, New York, NY.

Ohno, T. (1998), *Toyota Production System: Beyond Large-Scale Production*, Productivity Press.

Pyzdek, T. (2001), *The Six Sigma Revolution*, McGraw-Hill, New York, NY.

Radnor, Z., 2000. "Changing to a Lean Organisation: The Case of Chemicals Company", *International J. Manufacturing and Technology Management*.

Robinson, A. (1990), *Modern Approaches to Manufacturing Improvement*, Productivity Press, Portland, OR.

Smalley, A. (2006), *A Brief Investigation into the Origins of the Toyota Production System*, Art of Lean, Inc.

Stamm, M.L., Neizert, T.R., Singh, D.P.K. (no date), *TQM, TPM, TOC, Lean and Six Sigma - Evolution of manufacturing methodologies under the paradigm shift from Taylorism/Fordism to Toyotism*, AUT University, School of Engineering, Auckland, New Zealand.

7.4. Other Websites

"A Bomber An Hour" - *http://www.strategosinc.com/willow_run.htm* - Retrieved on 5 June 2016.

"A Brief History of Lean Manufacturing", *http://www.strategosinc.com/just_in_time.htm* - Retrieved on 5 June 2016.

"Goldratt - Operations - Drum Buffer Rope", *http://www.goldratt.co.uk/resources/drum_buffer_rope/* - Retrieved on 5 June 2016.

"History of Lean Manufacturing | Lean Manufacturing Tools", http://leanmanufacturingtools.org/49/history-of-lean-manufacturing/ - Retrieved on 5 June 2016.

"Japanese Economic Takeoff After 1945", *http://www.iun.edu/~hisdcl/h207_2002/jecontakeoff.htm* - Retrieved on 5 June 2016.

"Muda, Mura, and Muri | Lean Learning", *https://bobsleanlearning.wordpress.com/2010/01/14/muda/* - Retrieved on 5 June 2016.

"Muda Mura and Muri | Lean Manufacturing Wastes | Lean Manufacturing Tools", *http://leanmanufacturingtools.org/71/muda-mura-and-muri-lean-manufacturing-wastes/* - Retrieved on 5 June 2016.

"Six Sigma Methods, Tools & Techniques - Discover 6 Sigma - Online Six Sigma Resources", *http://www.discover6sigma.org/cat/methods-tools-techniques/* - Retrieved on 5 June 2016.

"The Origins of Just-In-Time - Quality and Innovation", *https://qualityandinnovation.com/2010/10/13/the-origins-of-just-in-time/* - Retrieved on 5 June 2016.

"The Origins of Lean Six Sigma | BPM, Lean Six Sigma & Continuous Process Improvement | Process Excellence Network", *http://www.processexcellencenetwork.com/lean-six-sigma-business-transformation/articles/the-origins-of-lean-six-sigma/* - Retrieved on 5 June 2016.

"TOC Thinking Processes - Theory of Constraints Institute", *http://www.tocinstitute.org/toc-thinking-processes.html* - Retrieved on 5 June 2016.

"Toyota Kentucky - History", *http://toyotaky.com/history.asp* - Retrieved on 5 June 2016.

"What is the Theory of Constraints, and How Does it Compare to Lean Thinking? | Lean Enterprise Institute", *http://www.lean.org/common/display/?o=223* - Retrieved on 5 June 2016.