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Wales Institute of Science & Art



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Title: Lean & Six Sigma Methodologies for Business and Process Improvement

Module: Quality and Business Improvement (ACMA4008)

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(May 2025).

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3 Introduction

The scope of this technical report is to discuss two of the industry leading methodologies for quality, business and continuous improvement that are currently being deployed around the world. These two methodologies are: -

1. Six Sigma
2. Lean Manufacturing

The objective is to discuss their origins, principles and their concepts. With further aims to discuss their evolution and implementation across all sectors of industry. This report will compare and contrast each approach to highlight their differences to quality and business improvement with reference to real world application of these approaches within my workplace.

4 Literature Review

4.1 Six Sigma Origins and Principles

Six Sigma (6σ) is a statistical approach to improving quality of products, services or processes. It is a data driven methodology that focuses heavily on the customer requirements by using a wide array of statistical, and mathematical methods to analyse collated data. 6σ aims to eliminate defects by reducing variation in products, services or processes without the need for intuition ('Think' or 'Feel'). The foundation to a 6σ approach in improving quality performance is in collating and analysing data using statistical methods as a definitive measure on where current performance lies and use data driven methods to improve performance.

A sigma (σ) is a mathematical measure of one standard deviation from the mean of a specific data set, or in other words a measure of deviation from expected parameters. The ideology of 6σ is that it is a mathematical measure of 'statistical perfection'. As can be seen in Figure 1. Producing quality products to a 6σ tolerance would provide defective free products 99.999998% of the time.

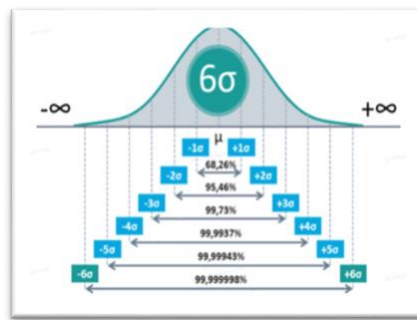


Figure 1 - Visual Illustration of the 6 Sigma Statistical Meaning (Anastasia, 2019)

6σ is widely accepted to be founded by Motorola in the 1990's by Bill Smith. Whilst Bill Smith was the first to describe the statistical approach to improving quality and combined a statistical methodology approach as 6σ . Neither Motorola nor Bill Smith created the underpinning statistical methods used to improve quality performance.

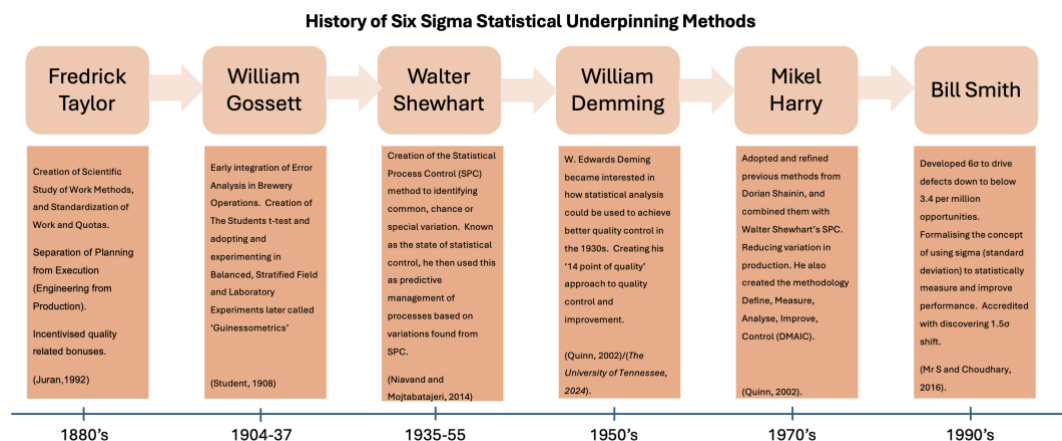


Figure 2 - History of the Six Sigma Statistical Underpinnings and Quality Principles

Some of the statistical and mathematical tools used within the 6 σ methodology can be traced through history and to origins that far predate Motorola.

Some credit Fredrick Taylor, who standardised work methods on data, not on 'feel' (Juran, 1992) as the beginning of statistical methods to improve quality in the 1880's. These foundations were then built on through to 1970 by William Gossett of The Guinness Brewery (Student, 1908), Walter Shewhart (*Niavand and Mojtatabajeri, 2014 & Moen and Norman, n.d.*), and William Demming (Quinn, 2002) (*The University of Tennessee, 2024*).

It was then in the 1970's through Mikel Harry, that Motorola did their part in combining Statistical Process Control (SPC), Shainin's advanced diagnostic tools (ADT) and planned experimentation (PE) (Quinn, 2002). To implement and create his own performance improvement approach. Known as Define, Measure, Analyse, Improve, Control (DMAIC).

This process was further refined by Bill Smith of Motorola in the 1990's when he combined some of these principles, and methods into a neatly packaged approach and defined a metric to strive for perfection 6 σ (Mr and Choudhary, 2016). He determined the specific and statistical range by which a company could measure how far they deviate from perfection, and where the name 'Six Sigma' was first used.

Why 6 σ is so powerful to use as a metric is it defines acceptable levels of performance in one universally applicable unit. By using industry measures such as Defects per Million Opportunities, Defects Per Unit (DPU), Rolled Throughput Yield (RTY) and Parts Per Million (PPM) any industry can measure themselves against a 6 σ operating level, regardless of their industry sector.

Sigma Level	DPMO	Industry Standard
6 σ	3.4	World Class
5 σ	233	
4 σ	6210	Industry Average
3 σ	66,811	
2 σ	308,770	Non-Competitive
1 σ	697,672	

Figure 3 - Sigma Level Performance Metrics

Using this simple metric of variation from target parameters 6 σ offers companies the chance to benchmark current levels of performance, and goal level performance. What Bill Smith also worked out was that any manufacturing process' short- and long-term performance will 'drift' over time (Bothe, 2002).

Mathematically 99.999998% quality performance equates 2 Defects Per Billion Opportunities (DPBO). But when a sigma shift is including into the calculation it equates to 3.4 Defects Per Million Opportunities (DPMO). Hence why it is lauded as statistical perfection for any manufacturing process.



Figure 4 - Sigma Shift Illustration (Team, 2017)

4.1.1 Six Sigma implementation Approach

Implementation of Six Sigma is achieved through a process called DMAIC – Define, Measure, Analyse, Improve, Control. A process of 5 phases aimed at removing, resolving, or at minimum mitigating unwanted variation. A key fundamental to any DMAIC project is that it is results-focused and driven by data, facts and metrics. Using this approach six sigma aims to identify and analyse a cause for variation, as well as standardise and control an improvement initiative.

4.1.1.1 DMAIC Approach Explained

Define Phase

Establish the project's scope, objectives, and customer requirements to align Six Sigma efforts with business goals and clearly articulate the problem to be solved. Establish current process performance and baseline metrics to quantify the scope of the problem and set improvement targets (Brook, 2017).

Analyse Phase

Identify, validate, and prioritize potential root causes of defects using structured, data-driven analysis (Brook, 2017). It is within this phase that the many statistical and mathematical tools are used to measure, quantify and find patterns (or lack thereof) within collated data, to find root causes of variation. Tools such as histograms, pareto analysis, SPC, and Machin Capability studies.

Improve Phase

Develop, test, and implement robust solutions to eliminate validated root causes and optimize process performance (Brook, 2017).

Control Phase

Sustain and institutionalize improvements by monitoring performance, standardizing processes, and embedding controls (Brook, 2017).

See Figure 5 for implementation action and potential tools used

Lean & Six Sigma Methodologies for Business and Process Improvement

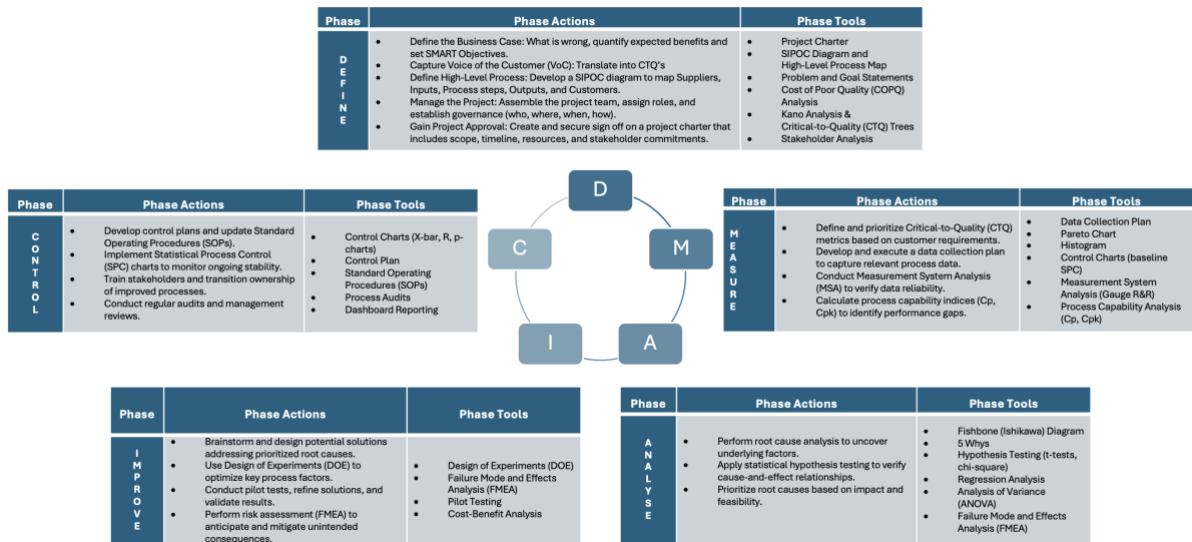


Figure 5 - DMAIC Process and Tools for implementation

4.2 Lean Manufacturing Origins and Principles

Lean Manufacturing is a continuous improvement methodology that is aimed at maximising productivity whilst simultaneously reducing waste within a manufacturing operation or process. The application of Lean Manufacturing requires analysing and improving the flow of materials and/or resources (time, people, funds etc..) to increase work efficiency. Anything that doesn't add value to the product should be considered a form of waste (Muda). It is by eliminating, or reducing these sources of waste in all their forms that maximises value added activities or processes and therefore improves production efficiency in a manufacturing operation. The Lean Methodology is encapsulated in a framework known as the 'House of Lean' as seen in Figure 6.

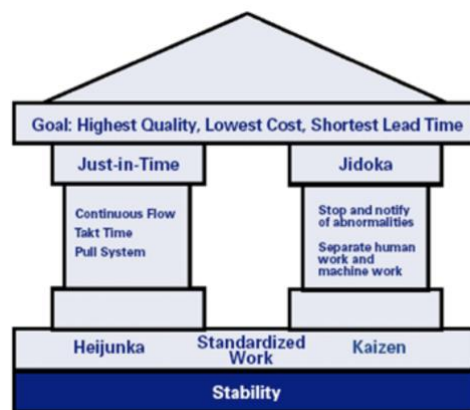


Figure 6 - House of Lean Manufacturing and its Pillars (devteam, 2006)

The term 'Lean Manufacturing' was first coined by Womack and Jones in their book, 'The Machine that Changed the World' in 1990. They didn't create this methodology or the processes within, but they reshaped and formed a methodology based on principles that have their origins in the history of manufacturing and brought it to a worldwide audience. The most credible and academically accepted founders of Lean Manufacturing principles is attributed to Toyota. Their methodology being known as the Toyota Production System (TPS). What Womack and Jones did was study, adapt, and add a few principles to the TPS approach. In doing so making it more easily and readily applicable to multiple industries including healthcare (Womack, Jones and Roos, 1990).

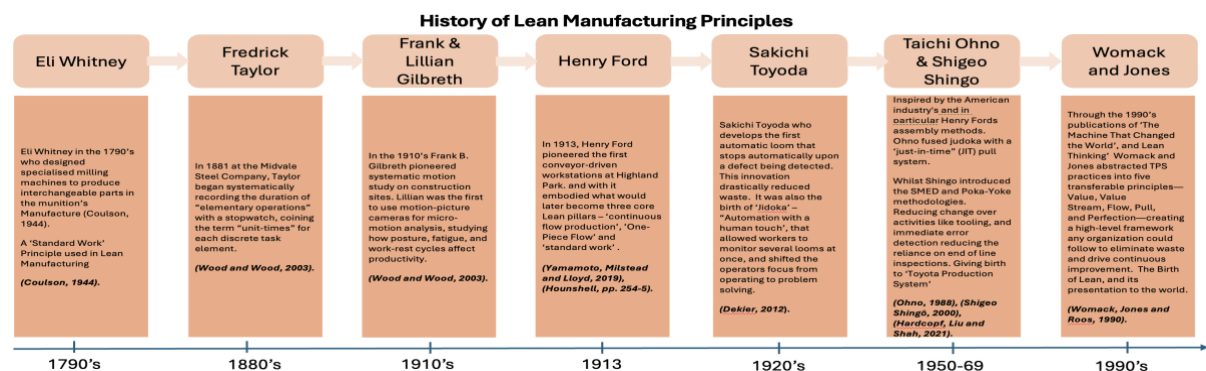


Figure 7 - History Lean Manufacturing Principles

All that said, Toyota themselves evolved methodologies and improvement techniques that can be traced in their origins far earlier. See Figure 7.

Some of the first measurable principles used in the Lean Manufacturing methodology can be traced back to Eli Whitney in the 1790's. Although some scholars do in fact refute this and put forward Simeone North as the pioneer (Coulson, 1944).

Through the 1880's to the 1910's Fredrick Taylor, Frank and Lillian Gilbreth respectively experiment with time and motion studies/testing.

In 1913 Henry Fords' new production line incorporates what would later become three core pillars of Lean Manufacturing

The next big step and turn towards Japanese industry was made in the 1920's by Sakichi Toyoda with the automated Loom.

From 1950 through to 1969 is where quality improvement through waste management really took off in the Japanese Automotive Industry. The conception and implementation of many methodologies that would become the Toyota Production System were born in this era with Taichi Ohno. Key concepts like Just-in-Time (JIT) and Kanban Scheduling. With the Elimination of the 'seven wastes' - Muda and 'Kaizen' - Continuous Improvement (Ohno, 1988).

During this time Shigeo Shingo's contribution was through methodologies such as Single-Minute Exchange of Die (SMED), Poka-Yoke (Mistake Proofing) and Zero Quality Control (Hardcopf, Liu and Shah, 2021), (Shigeo Shingō, 2000).

The TPS System at this point had developed into an approach to improve quality performance in the Japanese Automotive Industry, some of the Japanese named principles remain. However, in the 1990's with the release of the book "The Machine that changed the World" James P. Womack, Daniel T. Jones, and Daniel Roos gave to the world an adapted version of TPS that could fit within the confines of almost any business sector and improve efficiency and quality with continuous improvement initiatives that eliminate waste. Lean Manufacturing Methodology's evolution from TPS can be broken down to 5 key principles: -

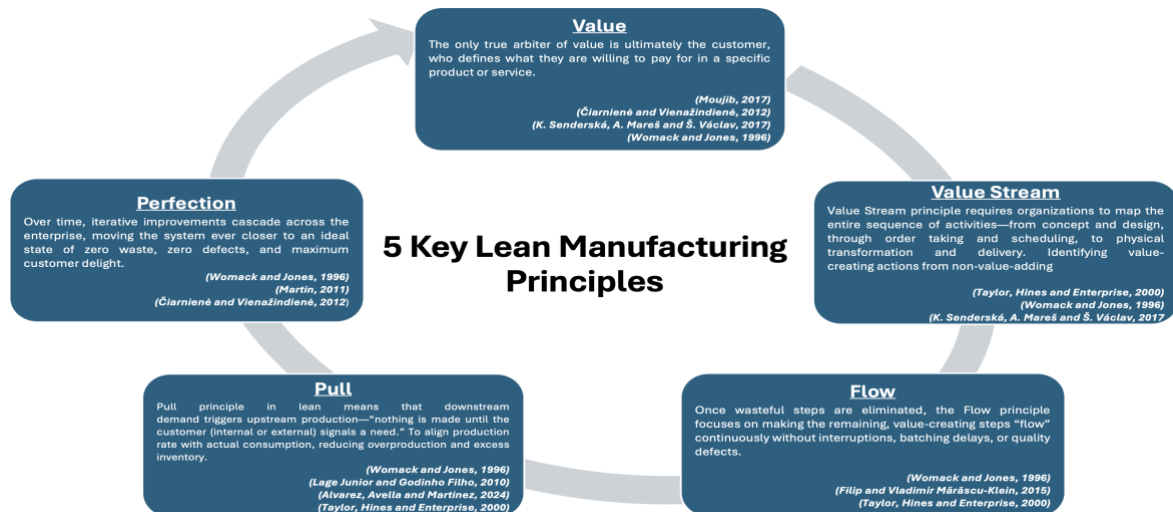


Figure 8 - 5 Key Lean Manufacturing Principles

Lean thinking methodology is about ensuring the customer requirements are being met for the product, process or service they are paying for. Ensuring that all efforts throughout the organisation are aligned towards this final endeavour, with limited to no activities, processes or procedures that either take away or minimise the effectiveness and efficiency of this endeavour.

Lean Thinking identifies 3 categories of waste that can impact an industry’s efficiency at meeting customer requirement/demands. Removing, minimising or mitigating these wastes is the bedrock of this approach into quality and business improvement. See Figure 9.



Figure 9 - 3 Waste Categories of Lean Thinking

These three waste categories are further broken down into eight waste types. These are what an organisation needs to address to become leaner, in a lean manufacturing approach.

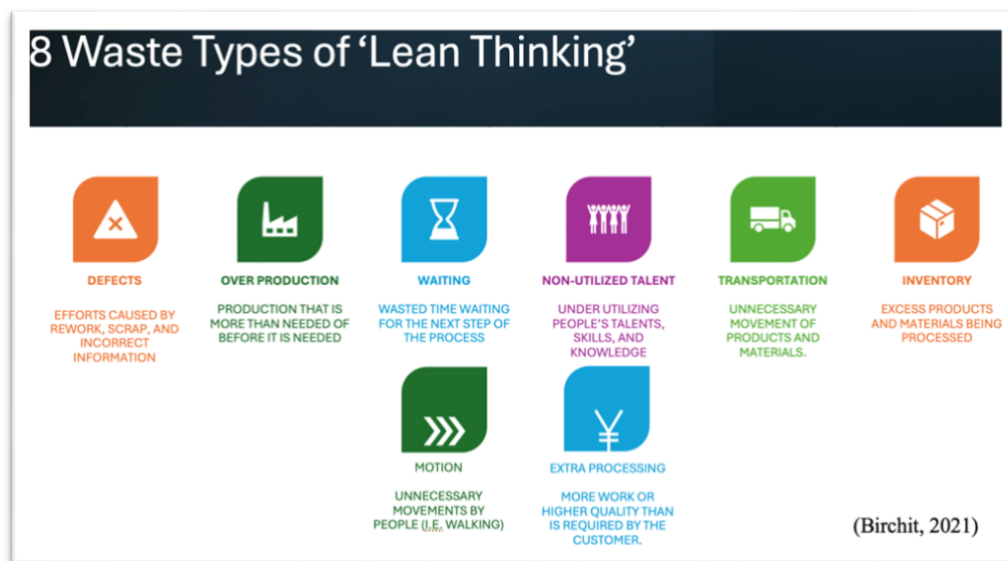


Figure 10 - 8 Types of Waste in a Lean Manufacturing Approach

4.2.1 Lean Implementation Approach

The way 'Lean' is implemented is via the 'House of Lean' approach (as was seen in Figure 6). The first step of which is an operationally stable manufacturing process. The end goal is highest quality, lowest cost and shortest lead time to produce the product or service for the customer. The house is built using the following methods and tools upon this first foundation of a stable operating process.

There is a blending of the tools used within the house of lean implementation, because each tool has a breadth of capacity to be applied in different phases. Fundamentally, the foundation principle is about standardising practices, and procedures to build improvement on.

Table 1 - Foundation Principle of House of Lean

HOUSE LAYER	HOUSE APPROACH	KEY PRINCIPLES	KEY TOOLS
FOUNDATIONAL	Kaizen – Japanese for change for the better ['Kai' = Change, 'Zen' = Good]	Kaizen is the continuous improvement cycle approach, where incremental improvements are introduced, implemented and then standardised. 3 Core principles of Kaizen are; - <i>Good housekeeping</i> , <i>Elimination of 'Muda'</i> and <i>Standardisation</i> .	• PDCA – Plan, Do, Check, Act Cycle of implementing the Kaizen. • 5S – To organise and standardise the workspace [Seiri (Sort), Seiton (Set in Order), Seiso (Shine), Seiketsu (Standardise), Shitsuke (Sustain)]
	Heijunka – Process Levelling	Heijunka aims to level the production by producing the correct product type, and volume by making optimal use of the manufacturing process capacity. Smoothing out or eliminate 'peaks' and 'troughs'. As well as ensuring resources are not under/over utilised, process demand is balanced and reduce unnecessary inventory.	• Heijunka Box/Board – Visual scheduling tool to balance demand for optimal flow. • SMED – to minimise downtime for tooling changes • Poke-Yoke – Error Proofing • Takt Time/Cycle time – Time to achieve customer demand Vs Actual production times.
	Standard Work	No improvements can be made sustainably without standardisation. Standards for procedures, practices, processes, tools, materials etc....	• Standard Work Charts/Combination Tables • Job Instruction • Supplier Standards/Materials Management • Value Stream Mapping • PDCA/Kaizen • Heijunka/Takt Time

Once the foundations have been laid, the lean approach can then align itself with the two pillars. To become more efficient and effective by maximising resource usage (time, capital, materials and people etc.)

Table 2 - Just in Time Pillar (JIT) of House of Lean

HOUSE LAYER		HOUSE APPROACH	KEY PRINCIPLES	KEY TOOLS
J U S T I N T I M E	P I L L A R	Continuous Flow - The aim of the ' Just in Time ' pillar in Lean is to adopt a continuous flow approach, with little to no disruptions in waiting, processing, and delivery times. Adopting procedures, and practices that enable continuous flow of production in line with a levelled and optimised balance of demand from the customer and processing capability.	Pull System – to achieve continuous flow the lean approach needs to adopt a pull system of production. Where upstream processes only produce in response to a signal from the downstream processes (Kanban).	• Kanban cards or electronic Kanban for visual production signalling. • Level production (Heijunka) boxes to smooth production schedules and mitigate spikes • SMED • Flow Cells & U- Shaped Lines – Grouping of operations of one product into a compact loop to minimise walking, transports, handover etc. Lage Junior and Godinho Filho, 2010) (Alvarez, Avella and Martinez, 2024) (Lage Junior and Godinho Filho, 2010) (K. Senderská, A. Mareš and Š. Václav, 2017)

The just in time pillar is primarily based around ensuring that a process is only operating as a direct result of the customer (External or Internal) requiring it to do so. This ensures no overproduction (Muda). It also aims to be as efficient and effective as possible within the appropriate time frame, no waste in waiting, handing over, transportation or tool changes etc.

The second Lean pillar is around quality control, and an approach to it that empowers the workforce to halt production at reduced quality production to protect the customer (Andon). Like all true innovative industries, the processes also include an error proofing aspect where appropriate to prevent human errors (Poka-Yoke).

Table 3 - Jidoka Pillar of House of Lean

HOUSE LAYER		HOUSE APPROACH	KEY PRINCIPLES	KEY TOOLS
J I D O K A	P I L L A R	Jidoka is often translated into 'Automation with a human touch', or 'Intelligent Stoppage'	The principle of which is to build quality into the product or process at source, in a way that any abnormality immediately halts production and prevent defects from flowing downstream.	• Poka-Yoke – Systems that remove the risk of human error. Physically designing the product, process or equipment in such a way incorrect operations cannot be performed. • Andon – Empowering workers to stop production on discovery of potential quality issues. Andon Lights have been adopted as VM of a process status (Red, Amber, Green) • Separate Human Work and Machines Work – Autonomation is phrase carried over from TPS and means to automate with a human touch. To automate the laborious or time-consuming tasks and free up the worker to make more Kaizen and empower decision making and innovation.

These are the fundamental steps to implement a Lean Manufacturing methodology to a manufacturing process to successfully achieve the end goal of lean 'highest quality, lowest cost and shortest lead time'

5 Conclusions

These two continuous improvement approaches do in fact have some similarities, and a shared history through time, however there are some stark differences too. Both approaches are a blend of Western and Japanese manufacturing improvement philosophies, based on methods and tools honed over centuries of production in the West and in Japan. Both aim to continuously improve a manufacturing process to meet a customer demand, and both were adapted, readopted and implemented throughout all industries the world over.

The difference between them and what has been seen through this report is the Six Sigma approach is aimed at reducing variation in a process to eliminate or minimise defects. Variation within a machine, process or processing unit, inside of a manufacturing process is what is identified as a primary source of defects. The Six Sigma approach uses a variety of statistical and mathematical methods to analyse data and uses a definitive measure to illustrate the rate of unwanted variation within a process. It also sets the very lofty goal of aiming for 6σ or statistical perfection within a manufacturing process

Whereas the Lean Manufacturing approach is heavily involved in reducing waste, and maximising effectiveness and efficiency with the resources available. A very succinct and small definition with huge consequence when adopted throughout an organisation at all levels. The approach is weighted on customer demand to create the pull system approach to a manufacturing process, and standardisation. These two are very powerful key elements in helping an industry or manufacturing process evolve and implement sustained continuous improvement.

Lean is a philosophy that is implemented at all levels, it includes and encourages active participation from the operator to engineers and of course the management. However, Six Sigma is usually undertaken at a higher level within an organisation, and any new methods to the process made on the back of its findings are usually standardised and implemented by management without the same level of participation from the operators.

Both approaches tackle quality, and drive improvement but in different and meaningful ways in my organisation (and it is probably not unique) we use both. We use Six Sigma as a methodology to improve our quality of the product, and we use Lean to maximise efficiency and effectiveness with the resources available. See Figure 11.

Improvement Type	Methodology Used	Comments
Drop Out Temperature – Reducing variation of drop out temperatures of steel slabs from the Reheat Furnaces	Six Sigma	Data analysed using array of methods looking for correlations.
Centre Line Deviation – Positioning of steel slabs during processing	Six Sigma	Variation found using statistical approaches
Surface Quality – Defect on surface of Steel Coils	Six Sigma	Analysing data from all processes to find correlation between defects and process
Housekeeping	Lean	5S Approach
Environment or Workplace Improvement	Lean	PDCA used to implement initiatives
Emergency Evacuation Procedures	Lean	Eliminating Muda to ensure effectiveness of all responsible people in an emergency Evacuation.

Figure 11 - Hot rolled products CI Initiatives and Methods Used

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