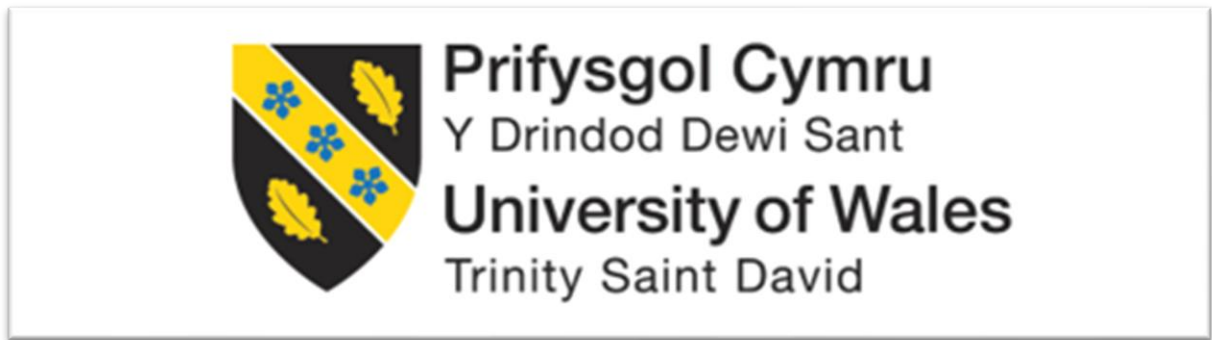


University of Wales Trinity Saint David.

School of Engineering.



Lean and Six Sigma methodologies for improvement of existing manufacturing processes.

Quality & Business Improvement (ACMA4008)

Connor Ward (2412295).

Engineering Management Degree.

03/05/2025

Abstract

The implementation of methodologies such as Lean and Six Sigma are vital to improve existing processes within a company. At BWE, there are various parts with different specification targets for a wide range of customers which can lead to processes not performing to its maximum potential. The principles behind Lean and Six Sigma differ regarding the data used and end goal but overall strive to achieve eliminating defects in products and providing customers with a high level of quality in the product. The implementation of Lean and Six Sigma can be done in isolation due to external factors that may prevent a successful implementation of either one. However, by combining both as Lean Six Sigma, it allows for a company to effectively eliminate waste within their process while implementing changes that will reduce variation within a process. Each concept has structured steps for implementation with the required tools to ensure that a company can maximise the benefits.

Table of Contents

1. Introduction	3
1.1 Objective of the Report.	3
1.2 The Importance of Lean in Manufacturing	3
1.3 The importance of Six Sigma	3
2. Literature Review	4
2.1 Introduction of Six Sigma	4
2.2 Introduction of Lean in Manufacturing.....	4
3. Six Sigma Methodology	5
3.1 Origin of Six Sigma	5
3.2 Statistical Six Sigma.....	6
3.3 Implementation of Six Sigma.....	7
3.3.1 DMAIC Approach	7
4. Lean Manufacturing Methodology	9
4.1 Origin of Lean	9
4.2 Lean Principles.....	9
4.3 Lean Implementation.....	10
5. Comparison of Six Sigma and Lean	12
6. Conclusion	13
7. References.....	14

List of Figures and Tables

Figure 1: Six Sigma history (Six Sigma Online, 2024)	5
Figure 2: Normal distribution curve with mean shifted by 1.5σ (Montgomery and Woodall, 2008)	6
Figure 3: 8 Types of Muda (Skhmot, 2017)	9
Table 1: Defect rate based on sigma level (Montgomery and Woodall, 2008).	6

1. Introduction

1.1 Objective of the Report

The scope of this report is to understand the principles and origins behind Lean and Six Sigma and how they are successfully implemented in a manufacturing environment. The report will aim to understand how these principles can be introduced at Blackwood Engineering (BWE). BWE is a castings and counterweights manufacturing company based in the UK. Due to large variation in parts and various specifications for different customers, processes and quality in certain circumstances can be underperforming to key performance indicators (KPI's). Understanding and utilising these principles at BWE will aid in improving underperformance and return to a sustainable path in reaching KPI's.

1.2 The Importance of Lean in Manufacturing

The methodology behind Lean can be significant to a manufacturing company. Companies using the principles behind Lean can produce high-quality products economically in lower volumes and bringing them to market faster than mass producers (Singh et al., 2014). This highlights that Lean can boost a company's productivity to beat lead times compared with rivals in that sector without incurring a huge loss to profits. Providing this service to customers can improve a company's reputation and increase customer base.

1.3 The importance of Six Sigma

Six Sigma implementation into a company's processes can improve overall performance. Six Sigma integration can impact the business performance, reduces costs, minimizes defects, and errors (Ramakrishna and Alzoubi, 2022). These are major advantages to a manufacturing company as being able to implement tools within Six Sigma to eliminate excess costs and variation within products are vital for success. A major takeaway from the importance of Six Sigma is minimising defects and providing customers with what they require.

2. Literature Review

2.1 Introduction of Six Sigma

The fundamental concept behind Six Sigma is improving processes by reducing defects and variability (Six Sigma Online, 2024). To have multiple process within a manufacturing company run efficiently, defects need to be eliminated as much as possible. The Six Sigma approach is based on the idea that a process should produce no more than 3.4 defects per million opportunities, which equates to six standard deviations (sigma) between the process mean and the nearest specification limit (Six Sigma Online, 2024). This outlines the standards that a manufacturing company should aim for. A company achieving this defect rate and deviation away from its process mean, highlights multiple well-controlled processes with limited variation and defects.

2.2 Introduction of Lean in Manufacturing

The idea behind Lean as a continuous improvement philosophy was developed for maximising resource utilization through the minimization of waste (Kumar et al., 2022). Continuous improvement of a manufacturing process is crucial. By constantly looking for ways to improve an existing process it can help to increase production and give a manufacturing company advantage, especially in a competitive market. A case study showing the benefits of Lean implementation from BAE Systems resulted in a 10% cost reduction on Hawk Lead in Fighter program and 7% cost reduction on Hornet deeper maintenance (BAE Systems, 2024). According to BAE Systems (2024) they managed to deliver this enhanced capability at a reduced cost without compromising on safety. This is an important observation on Lean, as continuous improvements enhances a company's performance without having a detrimental effect on safety which is vital to the principles of Lean.

3. Six Sigma Methodology

3.1 Origin of Six Sigma

Six Sigma has become vital for companies looking to improve performance by reducing variation in their products. According to (Antony, Snee and Hoerl, 2017) Six Sigma was developed at Motorola by Engineer Bill Smith in the 1980s as a business improvement approach that seeks to find and eliminate causes of defects in processes. Furthermore, (Antony, Snee and Hoerl, 2017) state that Six Sigma stemmed from Motorola in the 1980s while facing extreme pressure from overseas competition, particularly Japan. This highlights the invention of Six Sigma to provide Motorola a framework to improve their existing process to compete in a competitive market. However, despite Bill Smith being accredited with the creation of Six Sigma, the fundamentals of Six Sigma can be seen before this as shown in Figure 1.

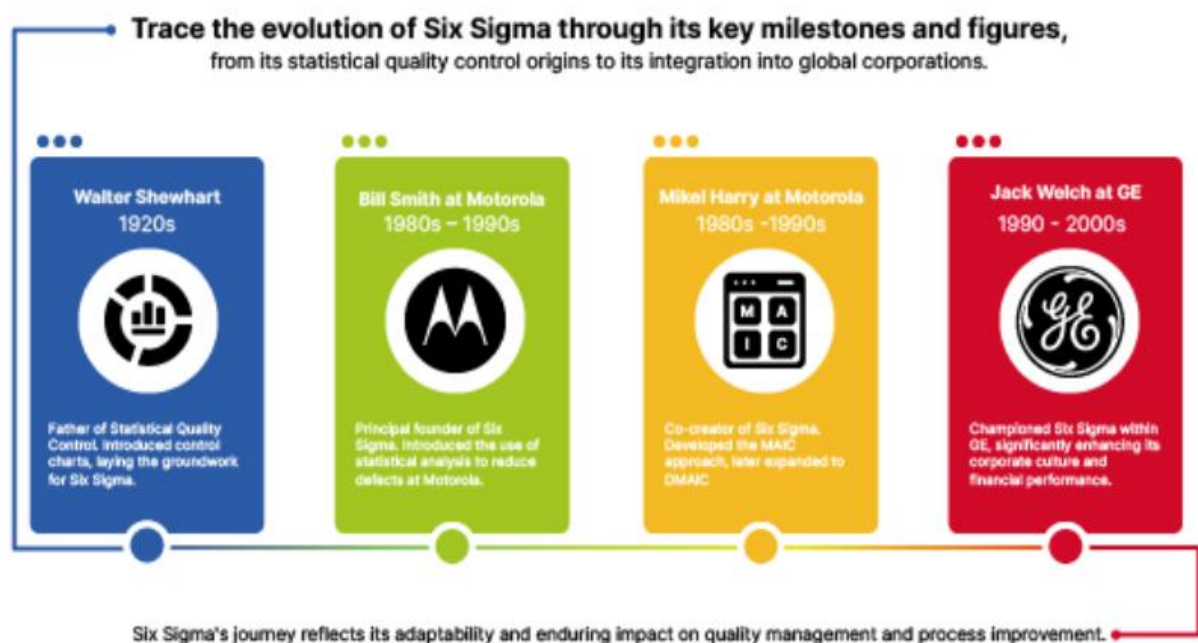


Figure 1: Six Sigma history (Six Sigma Online, 2024)

Figure 1 outlines Walter Shewhart as the “Father of Statistical Quality Control” and laid the groundworks for Six Sigma. Shewhart identified two types of variation, “assignable-cause” and “chance-cause” variation, which led Shewhart to devise the control chart as a tool for distinguishing the two (Best and Neuhauser, 2006). The ideology behind Six Sigma is to eliminate variation within a

product, which highlights the importance Shewhart's contribution. Figure 1 also underlines Six Sigma improvement with Mikel Harry at 1980s work introducing concepts that led to the DMIAC approach to implement Six Sigma. As well as this, Six Sigma enhancing financial performance at GE (General Electric) under Jack Welch in the late 1990's.

3.2 Statistical Six Sigma

One aspect of Six Sigma is statistical analysis. Sigma (σ) is the symbol that represents standard deviation used in statistics. Six Sigma as a statistical tool is used as a measure of ability of a process or process quality to produce the desired product (Mustafid et al., 2021). This is an important use of Six Sigma as a statistical analysis tool, as understanding the deviation within existing processes highlights where changes are necessary. To understand how a process achieves no more than 3.4 defects per million opportunities (Section, 2.2), Figure 2 shows a visual representation.

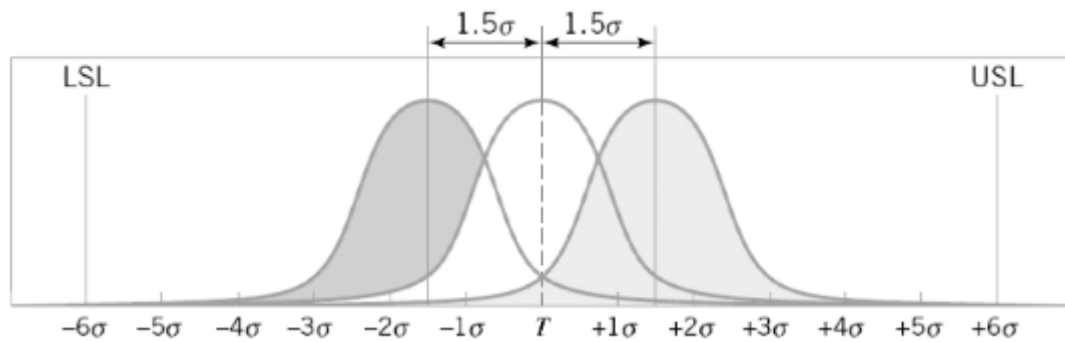


Figure 2: Normal distribution curve with mean shifted by 1.5σ (Montgomery and Woodall, 2008)

The concept behind Figure 2 is to reduce the variability in the process, so that the specification limits are at least six standard deviations away from the target (Montgomery and Woodall, 2008). This shows a tightly controlled process with less variation which will highly decrease the chance of defects. Figure 2 also highlights under Six Sigma that when a process reaches a 6σ level, the mean was still subject to disturbances that could cause it to shift by as much as 1.5 standard deviations off target (Montgomery and Woodall, 2008). Each σ level represents the number of defects within a product as seen in Table 1.

Table 1: Defect rate based on sigma level (Montgomery and Woodall, 2008).

Spec. Limit	Percent inside specs	ppm Defective
± 1 Sigma	30.23	697700
± 2 Sigma	69.13	608700
± 3 Sigma	93.32	66810
± 4 Sigma	99.3790	6210
± 5 Sigma	99.97670	233
± 6 Sigma	99.999660	3.4

Table 1 identifies that a highly controlled process with limited variation would be a 6 σ level resulting in 3.4 defective parts per million (PPM). A process achieving 1 σ level is not a controlled process due to the output being too widespread that only 30.23 of products produced are within the set specification limits. This statical analysis allows a company to understand the σ level they are currently operating at and understanding where existing processes need to be improved.

3.3 Implementation of Six Sigma

The key steps for implementing Six Sigma into a company's existing process is the DMAIC approach. DMAIC stands for "Define, Measure, Analyse, Improve and Control." Each of these steps are crucial and are supplemented with various tools that ensure a successful implementation.

3.3.1 DMAIC Approach

- Define Phase: This phase involves understanding customer requirements by looking at the required processes and setting boundaries of the project to be aligned with the process improvement. Tools used in this phase can be Project Charter, Project Schedule and CTQ (Critical to Quality) (Shaikh and Kazi, 2015).
- Measure Phase: To successfully measure the performance of the process, it is essential to develop a plan for data collection to identify types of defects and compare evidence to customer requirements. Tools commonly used in the measure phase are, Data Collection, Gage R&R Gage (Repeatability and reproducibility) and SIPOC (Shaikh and Kazi, 2015).
- Analyse Phase: Data analysis is implemented to understand where in the process defects are occurring Understanding current performance compared to goal performance to identify gaps, which highlights sources of variation that can be prioritized for improvement. Pareto Chart, Fishbone Diagrams and FMEA (Failure Mode and Effect Analysis) are necessary tools (Shaikh and Kazi, 2015).
- Improve Phase: Using the data collected in the "Analyse Phase," allows for improvement of the process to fix and prevent the problems. By implementing a plan, discipline and technology are used to develop innovative solutions supplemented by the following tools: Brainstorming, Design Changes and DOE (Design of Experiment) (Shaikh and Kazi, 2015).

- Control Phase: A crucial phase in the DMAIC approach by controlling and sustaining implemented improvements. This involves developing and implementing an ongoing monitoring plan that ensures improvement actions are understood with the correct training in conjunction with tools such as, Control Charts, Process Capability Six Pack and Hypothesis Testing (Shaikh and Kazi, 2015).

4. Lean Manufacturing Methodology

4.1 Origin of Lean

Lean as a continuous improvement philosophy has become an integral part of numerous manufacturing companies. Lean's focus on maximising resource utilisation through the minimization of waste (Section, 2.2) is a major benefit to these companies. Lean concepts can be dated back to the 1450s to the Arsenal in Venice, however the first big milestone was Henry Ford (Lean Enterprise Institute, 2023). In the 1910's Ford married consistently interchangeable parts with standard work and moving conveyance to create what he called flow production (Lean Enterprise Institute, 2023). Another key figure in Lean is Kiichiro Toyoda from Toyota. Toyoda in 1930s revisited key innovations from Ford in which a series of simple innovations could provide both continuity in process flow and a wide variety in product offerings which led to the implementation of the Toyota Production System (TPS) (Lean Enterprise Institute, 2023). According to (Lean Enterprise Institute, 2023) Toyota are the leading lean exemplar in the world and stands to become the largest automaker in the world. This highlights the benefits of Lean, providing Toyota the tools to be a market leader in the automotive industry. The actual word "Lean" was made popular by authors Womack, Jones, and Roos (1990) in the influential book entitled *"The Machine that Changed the World"*. This book brought Lean principles into the global spotlight and highlighted the dramatic performance gap between Japanese and Western car producers (Samuel, Found and Williams, 2015). The performance gap indicated to manufacturers that Lean implementation is vital and evidence that it can improve existing processes.

4.2 Lean Principles

The focus of Lean is minimising waste within a process to reduce cost as well unnecessary activities. These wastes are known as "Muda" and are a key part of the TPS (Skhmot, 2017). The eight main types of Muda can be seen in Figure 3.



Figure 3: 8 Types of Muda (Skhmot, 2017)

Figure 3 highlights the eight Types of Muda and how they affect a process. These types of Muda are where Lean is implemented to reduce their effect on the end product. Muda such as “Waiting” demonstrates a poorly designed process which results in those involved waiting around for the product or material needed. Unused talent which outlines the underutilisation of individuals talent and skills was not recognised as waste until the 1990s when the TPS was adopted in the West (Skhmoet, 2017). At BWE, the biggest identifiable type of Muda is “Inventory”. Due to factors such as customer schedules constantly changing, a large excess number of parts need to be stored to deal with this variation. According to (Skhmoet, 2017), this can lead to product defects, greater lead time in the production process and problems being hidden away in inventory. This provides a suitable continuous improvement project by implementing Lean principles to prevent excess material not being used. One of the most negating impacting Muda is Overproduction. According to Chiarini (2014, pg. 20), overproduction is one of the biggest problems manufacturing companies face. This is further supported by the developer of these Muda concepts, Taiichi Ohno at the time Toyotas chief engineer who stated that overproduction was the most serious of all the wastes because it was the root of so many problems (Bicheno, 1994). This provides a manufacturing company an understanding of how these concepts that could viewed as positive by producing high quantities of products, form waste that can be resolved with Lean implementation.

4.3 Lean Implementation

There are five main principles to implementing Lean that were defined from Womack, Jones and Roos (1990) *“The Machine That Changed the World”* (4.1). These principles visually can be seen in Figure 4.



Figure 4: The Five Lean Principles (Do, 2017)

- **Define Value:** Understanding what the customer requires from the product and the financial aspect is important. A customer might not know what they specifically require from the supplier. After further engagement with a customer using tools such as interviews, surveys and web analytics, the customers' needs are understood regarding how they want the end results and the final cost (Do, 2017).
- **Map Values Stream:** To understand where in the process unnecessary activities are occurring, it is important to map out the current process. Activities within the process that do add value to the product are considered waste in the process. Eliminating these sources of waste within the process is necessary as it allows the product to be produced to the same standards while also incurring less cost (Do, 2017).
- **Create Flow:** When unnecessary waste has been removed from the process, the process must run efficiently with the new changes. These activities are referred to as value-adding activities and can run smoothly by levelling out the workload and ensuring that all employees are trained to be multi-skilled and adaptive (Do, 2017).
- **Establish Pull:** Inventory is considered one of the biggest wastes in any production system (Do, 2017). A pull system allows a supplier to implement just in time (JIT) delivery which allows for products to be produced according to the customer and not over produce and fill up inventory. This is supplemented by storing just enough stock to meet these requirements and not overstocking. By working backwards through the process, it allows for certainty that the products at the end result will be up to the customers standards (Do, 2017).
- **Pursuit Perfection:** The last principle is key to maintaining the performance improvements implemented and eliminating waste. It creates an environment in the workplace where continuous improvement is shared among all members involved in the process to continuously look for and eliminate waste. As well as this, ensuring that the process involved are aiming to satisfy the customers' requirements (Do, 2017).

5. Comparison of Six Sigma and Lean

Both principles have been widely adapted by companies globally to improve their existing processes efficiency and reduce their waste (Alhuraish, Robledo and Kobi, 2017). They have also been used in conjunction as “Lean Six Sigma” by combining Leans waste elimination focus with Six Sigma’s quality and variability control to make a process both efficient and defect-free (Croft, 2025). A company will need to understand the compatibility of these methodologies to their existing process and plan how and when to implement each one (Alhuraish, Robledo and Kobi, 2017). Without understanding these factors, the company may not achieve the benefits that lean manufacturing and/or six sigma can yield (Alhuraish, Robledo and Kobi, 2017). The tools used in each of these methodologies are used to different outcomes. Lean implements tools such as JIT, 5S and continuous improvement to eliminate waste within in a process. Six Sigma tools however are statistical and analytical tools such as control charts and process mapping to eliminate defects and variations in processes (Team, 2024). Data within Six Sigma looks at the current state of the process with data such as cycle times and defect rates, which is then scrutinized with statistical tools such as hypothesis testing and regression analysis to identify correlations and determine root cause of defects (Ryan, 2024). Lean uses Value Stream Mapping to visualise an entire process of a product and collects data such as waiting times and inventory levels to identify bottlenecks and non-value-added activities (Ryan, 2024). This highlights a contrast between the way both methodologies use the data they collect to improve the process. Six sigma is primarily data driven using quantitative data to perform statistical analysis, with a primary focus on reducing variation and defects, whereas Lean uses quantitative data, but it focuses more on process flow and efficiency eliminating waste and improving flow (Ryan, 2024). The skill level to participate in these methodologies is a key difference. Lean uses the expertise of all employees for continuous improvement whereas Six Sigma requires specialised training and certification for Yellow, Green and Black Belts (George and Creately, 2024). This allows Lean to be adopted companywide for continuous improvement whereas Six Sigma can only be done by a handful of people. This limits the capability of utilising all employees’ skills (Section, 4.2) and prevents creating an environment where everybody is responsible for continuous improvement.

6. Conclusion

In conclusion, both Lean and Six Sigma are essential methodologies that should be adopted by companies within any sector. Lean's focus on waste elimination allows for companies to reduce costs associated with their product (Section, 2.2) and continuously implement changes within their process to sustain this. Six Sigma's core foundation of improving processes by reducing defects and variability (Section, 2.1) allows the potential for a company to reach a 6 σ level and reach defect rate of 3.4 defects per million opportunities. The steps behind each of these principles, DMAIC and the 5 Lean principles, provide a framework for companies to understand each step of implementation and the tools used to successfully complete each step. At BWE, a large source of waste was identified as over-inventory due to uncertainty in customer schedules (Section, 4.2). This could be targeted with the 5 Lean Principles (Section, 4.3) by establishing a pull system through BWE's existing processes, an implemented change of JIT can be established inferring unnecessary cost. A DMAIC approach to a BWE process would require more personnel to be trained to a black and green belt standard (Section, 5) but would be beneficial to improving performances in BWE's processes and quality and reach the targeted KPI's (Section, 1.1).

7. References

- Alhuraish, I., Robledo, C. and Kobi, A. (2017). A comparative exploration of lean manufacturing and six sigma in terms of their critical success factors. *Journal of Cleaner Production*, 164, pp.325–337. doi:<https://doi.org/10.1016/j.jclepro.2017.06.146>.
- Antony, J., Snee, R. and Hoerl, R. (2017). Lean Six Sigma: yesterday, today and tomorrow. *International Journal of Quality & Reliability Management*, 34(7), pp.1073–1093. doi:<https://doi.org/10.1108/ijqrm-03-2016-0035>.
- BAE Systems (2024). [online] Baesystems.com. Available at: <https://www.baesystems.com/en/our-company/our-businesses/bae-systems-australia/defence-solutions/solutions-in-the-air/lean>.
- Best, M. and Neuhauser, D. (2006). Walter A Shewhart, 1924, and the Hawthorne factory. *Quality and Safety in Health Care*, [online] 15(2), pp.142–143. doi:<https://doi.org/10.1136/qshc.2006.018093>.
- Bicheno, J. (1994). *The quality 50 : a guide to 8 gurus, 7 tools, 7 wastes, 6 new tools, 20 techniques, 2 systems*. Victoria, Australia: Nestadt Consulting Pty. Ltd.
- Chiarini, A. (2014). *Lean organization : from the tools of the toyota production system to lean office*. Springer.
- Croft, D. (2025). *What Is Lean Six Sigma? A Beginner's Guide To DMAIC & Tools*. [online] Learn Lean 6 Sigma. Available at: <https://www.learnleansigma.com/continuous-improvement/what-is-lean-six-sigma-a-complete-guide-for-beginners/>.
- Do, D. (2017). *The Five Principles of Lean*. [online] The Lean Way. Available at: <https://theleanway.net/The-Five-Principles-of-Lean>.
- George, C. and Creately (2024). *Difference Between Six Sigma and Lean: A Comprehensive Guide*. [online] Creately. Available at: <https://creately.com/guides/differences-between-six-sigma-lean/>.
- Kumar, N., Shahzeb Hasan, S., Srivastava, K., Akhtar, R., Kumar Yadav, R. and Choubey, V.K. (2022). Lean Manufacturing Techniques and Its implementation: a Review. *Materials Today: Proceedings*, [online] 64(3), pp.1188–1192. doi:<https://doi.org/10.1016/j.matpr.2022.03.481>.
- Lean Enterprise Institute (2023). *A Brief History of Lean*. [online] Lean Enterprise Institute. Available at: <https://www.lean.org/explore-lean/a-brief-history-of-lean/>.
- Montgomery, D.C. and Woodall, W.H. (2008). An Overview of Six Sigma. *International Statistical Review*, 76(3), pp.329–346. doi:<https://doi.org/10.1111/j.1751-5823.2008.00061.x>.

Mustafid, I. Yulvia, D. Ispriyanti, Sugito Sugito and Hakim, A. (2021). The use of statistical transformation in six sigma analysis. *Journal of physics*, 1943(1), pp.012156–012156. doi:<https://doi.org/10.1088/1742-6596/1943/1/012156>.

Ramakrishna, Y. and Alzoubi, H. (2022). Empirical Investigation of Mediating Role of Six Sigma Approach in Rationalizing the COQ in Service Organizations. *Operations and Supply Chain Management: An International Journal*, 15(1), pp.122–135. doi:<https://doi.org/10.31387/oscm0480335>.

Ryan, D. (2024). *Understanding The Role Of Data In 6 Sigma Vs Lean - Howinsights*. [online] How Insights. Available at: https://howinsights.com/understanding-the-role-of-data-in-6-sigma-vs-lean/#Here_are_the_role_of_data_in_six_sigma [Accessed 03 May 2025].

Samuel, D., Found, P. and Williams, S.J. (2015). How did the publication of the book The Machine That Changed The World change management thinking? Exploring 25 years of lean literature. *International Journal of Operations & Production Management*, 35(10), pp.1386–1407. doi:<https://doi.org/10.1108/ijopm-12-2013-0555>.

Shaikh, S. and Kazi, J. (2015). A Review on Six Sigma (DMAIC) Methodology. *International OPEN ACCESS Journal Of Modern Engineering Research*, [online] 5(2), p.11. Available at: <https://core.ac.uk/download/pdf/55305491.pdf>.

Singh, S., Sharma, K., Kumar, D. and Gupta, T. (2014). *Role & Importance of Lean Manufacturing in Manufacturing Industry*. [online] Available at: <https://theijes.com/papers/v3-i6/Version-5/A036501014.pdf>.

Six Sigma Online (2024). *The History of Six Sigma: from Motorola to Global Adoption*. [online] Six Sigma Online. Available at: <https://www.sixsigmaonline.org/six-sigma-history/>.

Skhmot, N. (2017). *The 8 Wastes of Lean*. [online] The Lean Way. Available at: <https://theleanway.net/The-8-Wastes-of-Lean>.

Team, E. (2024). *COVID-19 Situation: Six Sigma Ongoing Training Announcements*. [online] SixSigma.us. Available at: <https://www.6sigma.us/lean-six-sigma-articles/lean-vs-six-sigma/>.