IS SCIENTIFIC REASONING THE KEY TO LEAN SIX SIGMA'S SUCCESS?

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The Lean Six Sigma (LSS) process continue to be used throughout the public and private sectors to map processes seeking to make them lean and, thereby, more efficient and effective. We make the argument that the LSS process (i.e. Define, Measure, Analyze, Improve, and Control (DMAIC)) is inherently scientific. In Ronald N. Giere's (1979) book entitled Scientific Reasoning, he develops a scientific reasoning methodology and then applies the methodology to describe the process used to discover deoxyribonucleic acid (DNA). The article will overlay real-world LSS project conducted by an element of the United States Office of the Secretary of Defense (OSD) between 2006 and 2008 and its DMAIC process atop Giere's Scientific Reasoning Methodology. Ultimately, this article uses the scientific reasoning methodology to bound the evidence necessary to form the scientific explanation that the DMAIC process is indeed – scientific and the key to Lean Six Sigma's success.

Key words: *Lean Six Sigma (LSS), Science, and Six Sigma*

1. INTRODUCTION

Lean Six Sigma (LSS) is a process that seems to weld the proven lean and six sigma methodologies together, taking the best from each and leaving any non-value added steps behind. Many highly successful corporations have used LSS to improve their internal processes, which seems to have enhanced their profitability. Why? Perhaps, as cross-functional teams of engineers, accountants, and salesmen worked together on difficult internal organization issues, they began to apply their specialized educational backgrounds - backgrounds rooted in scientific methods. Ultimately, this interaction may have led to the operationalization (as defined below) (1) of LSS and the robust methodology we see today.

This paper will first describe LSS, showing how it evolved from discrete process/product improvement methodologies into its current form. Next, it will introduce Ron Giere's approach for scientific reasoning, with slight modifications made to improve clarity of explanation. Then, each phase of the LSS methodology will be laid atop the scientific method to demonstrate similarities between the two. Giere validated his methodology using the discovery of the structure of DNA by Watson and Crick as a scientific episode (Giere, 1979, pp. 32-37). Similarly, a LSS episode will be presented with comparisons made to the Watson and Crick episode to explain the overlap between the two methodologies. Finally, the conclusion will provide a summary of the adapted scientific reasoning/LSS methodology providing the explanation that supports the theory that the scientific reasoning is indeed the key to the success of LSS in both the public and private sectors.

2. LEAN SIX SIGMA (LSS)

Lean concentrates on controlling resources, reducing waste, and meeting the needs of the customer (Andersson, Eriksson, & Torstensson, 2006, p. 288). Lean's roots as a management improvement technique can be traced back to the Toyota production system developed in the 1950s (Arnheiter & Maleyeff, 2005, p. 9; Andersson, Eriksson, & Torstensson, 2006, p. 288). Lean's goal is to eliminate waste (i.e. muda in Japanese) so that any and all steps in the value stream for the product or service add value, thereby, reducing process time and increasing the velocity of the entire system (Arnheiter & Maleyeff, 2005, p. 9). The focus of these efforts is continuous or radical improvement events, known as kaizen and kaikaku in Japanese, respectively (Arnheiter & Maleyeff, 2005, pp. 9-10). Both kaizen and kaikaku are events set about to reduce waste or muda. These three elements are used together to place the organization, using lean, on an inexorable path to perfection. For example, US Army Recruiting and Accessions Command chartered a Subject Matter Expert (SME) team to look into their process for recruiting new soldiers and found that their As Is process had 32 steps. Through this lean process, they were able to reduce the steps to 11 in the To Be process, a 66% reduction (Reece, 2006). Lean seeks to remove non-value added steps keeping only those that add value and reduce cycle time within, or between, steps in a given process (Naslund, 2008, pp. 271-276; Stamm, Neitzert, & Singh, 2009).

Six Sigma began as elements of Total Quality Management (TQM). In the mid-1980s both Motorola and General Electric drew the Six Sigma elements out of TQM (Arnheiter & Maleyeff, 2005, p. 6; Stamm, Neitzert, & Singh, 2009). In due course, practitioners used the statistical elements of process/product improvement and an organized hierarchy of Six Sigma certified experts (i.e. Champions, Sponsors, Master Black Belts, Black Belts, Green Belts, and White Belts) to implement improvement efforts (Andersson, Eriksson, & Torstensson, 2006, pp. 286-287; Arnheiter & Maleyeff, 2005; Stamm, Neitzert, & Singh, 2009). Through this social structure, Six Sigma's certified expert hierarchy builds organizational buy-in into the product or process improvement efforts (Stamm, Neitzert, & Singh, 2009; Schroeder, Linderman, Liedtke, & Choo, 2008). This disciplined, socially structured, statistically based approach seems to have created value for both organizations.

When Six Sigma started with the Motorola Corporation in the 1987, the metric chosen to be measured and analyzed was defect rates, specifically, Defects Per Million Opportunities (DPMO). Motorola developed a Six Sigma program to reduce their DPMO to 3.4 defects per million, greater than 6σ (i.e. + and – 3σ), or the extreme end of one-tail in a normal distribution of sample products produced (Klefsjo, Wiklund, & Edgeman, 2001, p. 32; General Electric Company, 1999). Six Sigma represented the statistical variable of standard deviation (e.g. Sigma = σ) in Motorola's case DPMO became the focus of their improvement effort. Using a normal distribution in statistics, plus and minus 1 σ away from the mean will encompass ~ 68% of the sample measure of the population, plus and minus 2 σ away from the mean will encompass ~ 95%, and plus and minus 3 σ will encompass ~ 99%, as shown in Figure 1 below. As such, plus and minus 3 σ away from the population mean (μ) or 6 σ outside of one-tail in the bell curve in Figure 1 will include approximately (~) 99% as a sample measure of population captured, assuming the data follows a normal distribution. In this case, the 3.4 defects per million of the sample products produced, the six sigma measure that Motorola achieved. Hence, this statistical measure of 6 σ or Six Sigma became an integral part of the LSS name for this product or process improvement methodology.

Some authors like Andersson et al state that Six Sigma provides nothing new from what is contained in TQM (Andersson, Eriksson, & Torstensson, 2006, p. 283). Indeed, it provides less than TQM following the law of parsimony. It leaves only those essential elements that provide value, as one would expect. As LSS was operationalized over time into a process/product improvement methodology, only those value added elements remained. Elements that did not add value were culled or leaned out of the process as the law of parsimony (2) would dictate.

Early on, the parsimonious combining of Lean and Six Sigma began to show great promise in process improvement and product development starting in the 1990s.

The merger of Lean and Six Sigma first began at Allied Signal in the early 1990s. The company had started two process improvement methodologies separately. Lean was used to improve their process speeds and reduce their lead times on product delivery. Simultaneously, Allied adopted Six Sigma as a company-wide initiative. Initially, they were deployed separately, but they were eventually brought together under a single Vice President. As the initiatives were executed, it became apparent that leveraging the best in each would achieve greater gains for Allied (DeCarlo, 2005, pp. 57-59). During the same time frame, The Maytag Corporation leveraged the kaizen event methodology used by Lean, coupled with the stronger Six Sigma statistical analysis tools, to gain a competitive advantage. In a single quarter, Maytag executed 800 kaizen events that resulted in a 55 percent drop in production costs, saving more than $25 million dollars (DeCarlo, 2005, pp. 57-59). Both organizations achieved impressive gains in costs savings and efficiency. The operationalization of LSS had begun. (DeCarlo, 2005, pp. 57-59).

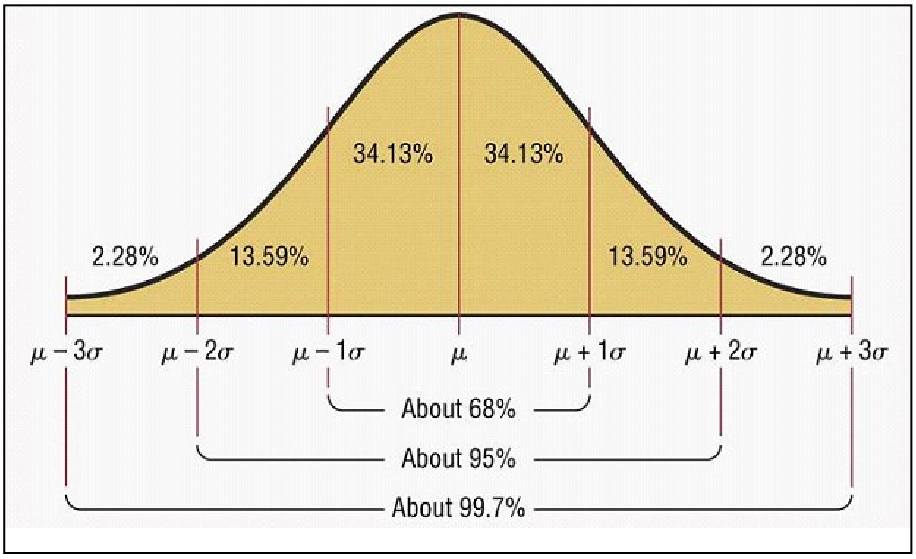


Fig. 1. Normal Distribution depicting the Population Mean (i.e. μ), Standard Deviations (i.e. σ), and percentage of the population encompassed by +/- σ away from the μ (Bowman, 2009).

Put simply, Lean did not have the rigorous statistical control procedures of Six Sigma. Furthermore, Six Sigma did not possess the dramatic product improvement approach of lean, which focused on improving process speed and reducing waste (Michael, 2002, p. xxi). Consequently, the two methodologies merged into what is now known as LSS, capitalizing on the strengths of each to create a powerful process and product improvement methodology (Arnheiter & Maleyeff, 2005, pp. 16-17; DeCarlo, 2005). The LSS methodological process is shown in Figure 2. This approach is broken into five phases: Define, Measure, Analyze, Improve, and Control, commonly known as the DMAIC process amongst practitioners.

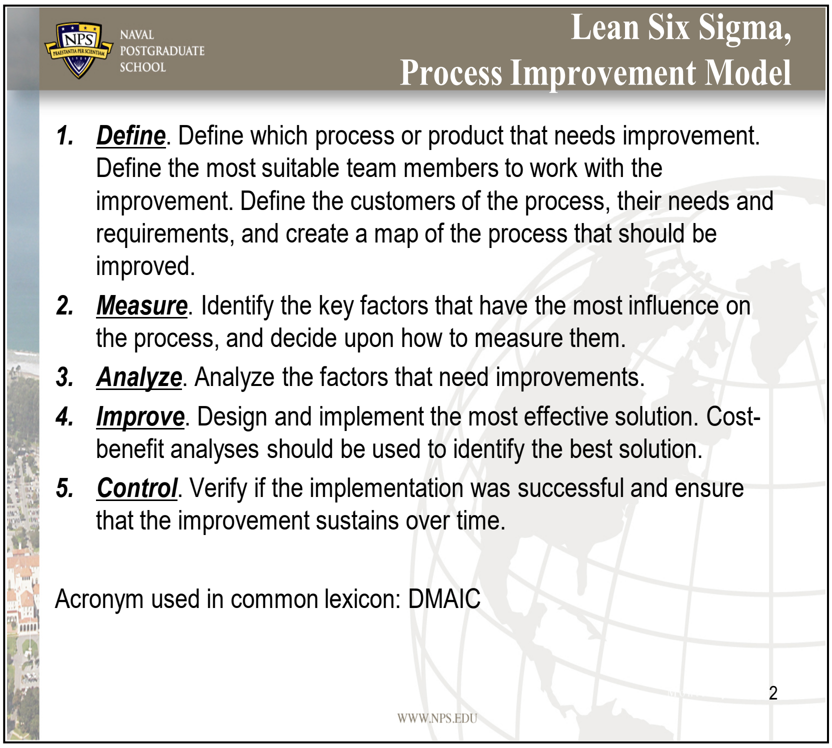


Fig. 2. LSS Process Improvement Model (Andersson, Eriksson, & Torstensson, 2006, p. 287; Magnusson, 2003)

This merger of Lean and Six Sigma is strikingly similar to the progress made between the late 1800s and the early 1900s in scientific philosophy when empiricist thought helped science progress and provided the fundamental ground work that enabled the logical positivists to take the next steps in the formulation of scientific thought (Godfrey-Smith, 2009, pp. 19-37). The logical positivists left behind what was flawed in empiricist thought but kept what aided them in advancing scientific thought and philosophy. Further, the logical empiricists built on the philosophy of the logical positivists, which enabled some of the great scientific discoveries of the last century. Just as science progressed and elements were operationalized to allow scientists to do their work, Lean and Six Sigma were operationalized to create a powerful, useful product/process improvement methodology, which appear to be scientifically based (Bogen, 2014; DeCarlo, 2005, pp. 57-58). The LSS phases is discussed in the next section overlaid atop Giere's scientific reasoning methodology to reveal the similarities between the two.

3. OVERLAY METHODOLOGY

Ronald N. Giere lays out a discrete technique for scientific reasoning as shown in the upper left of Figure 3 below. This paper's author chose to adapt Giere's methodology slightly, creating logical linkages shown in the lower right of Figure 3 in red, for the purpose of explanation and comparison with the LSS methodology. These linkages seem to be implied by Giere, but not specifically illustrated. As such, the Overlay methodology clearly depicts the steps necessary for explanation, comparison, and understanding.

Giere's method depicts four ingredients necessary to support a scientific methodology. These include: what the researcher is studying in the real world; the working model is meant to emulate the real world phenomenon; the data gathered through interaction with the real world; and finally, once the data is put into the model, a prediction is derived from the model. This prediction is compared with the data and the hypothesis to see if there is agreement. If there is, the hypothesis is supported by the model: the model fits accurately, predicting the real world phenomenon.

The first three phases of the LSS methodology (i.e. define, measure, analyze) cover all of Giere's ingredients of scientific reasoning, as depicted in Figure 3. In these phases, many of the same processes occur as the LSS team seeks to understand the real world phenomenon that may be preventing either efficient operations or effective product development. Initially, the LSS approach will be laid atop the adapted scientific reasoning method for purposes of comparison. The comparison begins with a discussion of the define phase of the LSS methodology.

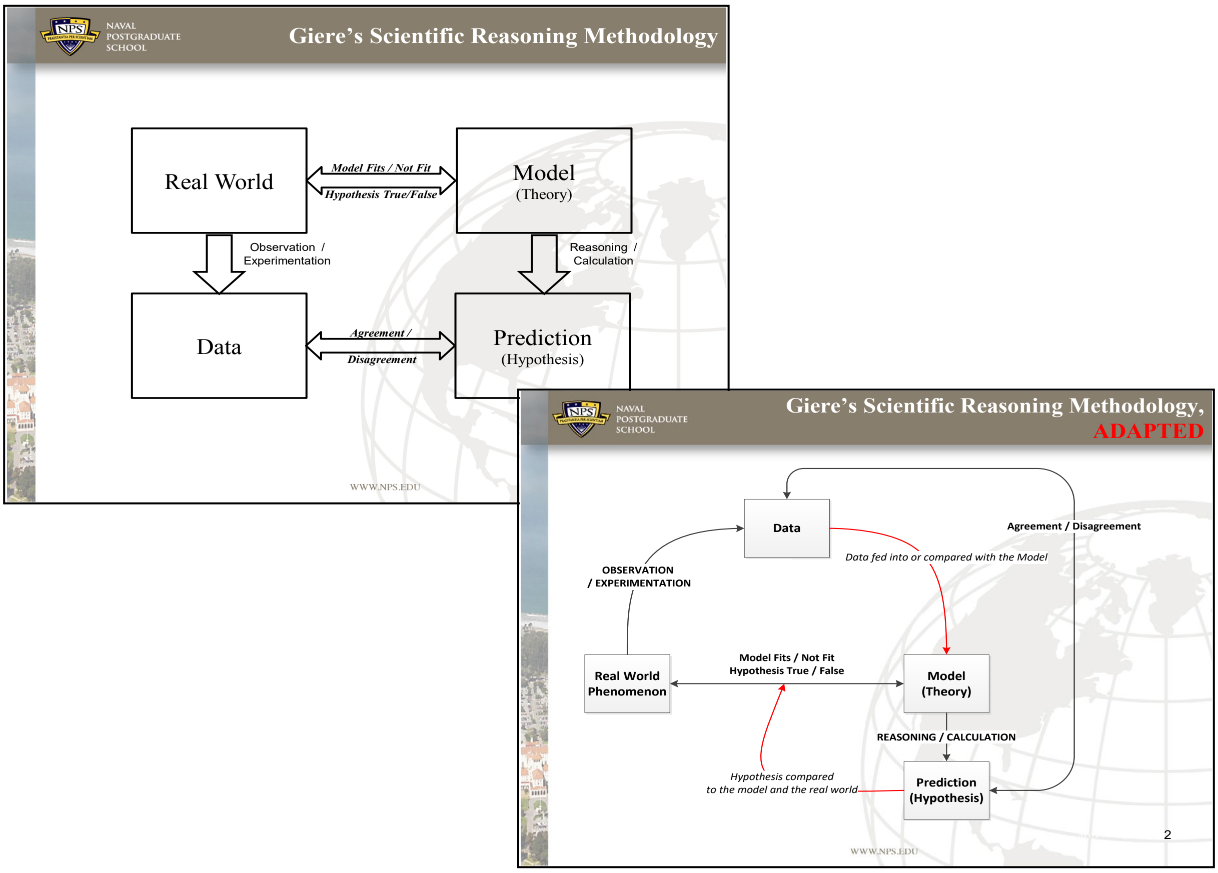


Fig. 3. Giere's Scientific Reasoning Methodology Original to ADAPTED (Giere, 1979, p. 32)

During the Define phase, a cross-functional team of SMEs is formed around the focus area (i.e. process or product) to be improved, seeking to delineate the current "As Is" process. At times, the "As Is" process or product may resemble an inefficient ad hoc process or quickly developed product. Most likely, the process put in place or product developed was put together by a group of people who were trying to find an expedient solution that would work temporarily or to develop a product quickly to get it to market. In most cases, the process has not been reviewed since or conditions in the marketplace necessitate a need to improve the product or process by which it was made. It is critical to define the As Is; this is when the team begins to understand where to look, scientifically in the real environment, for the data or information required by the subsequent steps.

As such, in the Define phase, the team examines the real world and seeks to develop an "As Is" model to emulate what is currently being observed. This encompasses the real world and model ingredients of scientific reasoning, circled in red below, because all of the same actions occur in the LSS methodology. For example, during the Define phase, the team is observing the real world phenomenon and begins to develop a theoretical model that closely approximates what is being observed. Initially, the team will collectively decide whether the model developed fits what is being seen in the real world, or not, and make the necessary adjustments to ensure that it does. Similarly, scientific reasoning begins with the observance of a phenomenon in the real (i.e.; empirical, tangible) world. Based on that observation, a theoretical model is developed that depicts how the real world phenomenon occurs in its environment.

Then, the team seeks to derive Measures that indicate the length of time used or the amount of resources expended to execute the “As Is” process used or product created. The Measure phase, circled in blue below, encompasses the data collected through observation/experimentation and then that data is fed into the previously developed model to determine whether it adequately fits the focus area or real world occurrence. Essentially, the LSS team gathers data from the focus area in its real surroundings. This is analogous to how a scientist gathers data about a given phenomenon in the real world environment knowing that two very specific characteristics must be met. First, the data must be acquired through a process of physical interaction with the real world, where that phenomenon being studied takes place. Second, both scientists and LSS team members should obtain this data through observation or experimentation of the phenomenon, while adhering to these two characteristics. These two characteristics remain necessary throughout the explanation and will be integral in the comparison of scientific reasoning to LSS.

Once the team ensures those prerequisites are met, they would input the data into the model and monitor its output through reasoning/calculation. The Measure phase is intended to scientifically breakdown the process or product concern into a discrete, quantifiable metric or set of metrics to ensure that the team is focused on the right area to eventually analyze, improve, and control – the subsequent LSS phases.

The analyze phase, circled in green above, covers all of the scientific reasoning ingredients because the interaction between these LSS phases becomes iterative until a working As Is model is developed that accurately reflects the focus area. First, it is necessary to discern if the data entered into the model during the Measure phase through reasoning/calculation results in the prediction the team expected and that the data and prediction are found to be in agreement. If this is true, then the team can safely say that the model seems to fit, emulating the actual environment - supporting the hypothesis. If not, the team will need to engage in an iterative process to ensure the data was gathered correctly, to check the model’s goodness of fit, or to determine if some pertinent element was left out of the model, preventing it from closely matching the real world phenomenon. Eventually, the prediction and the data agree.

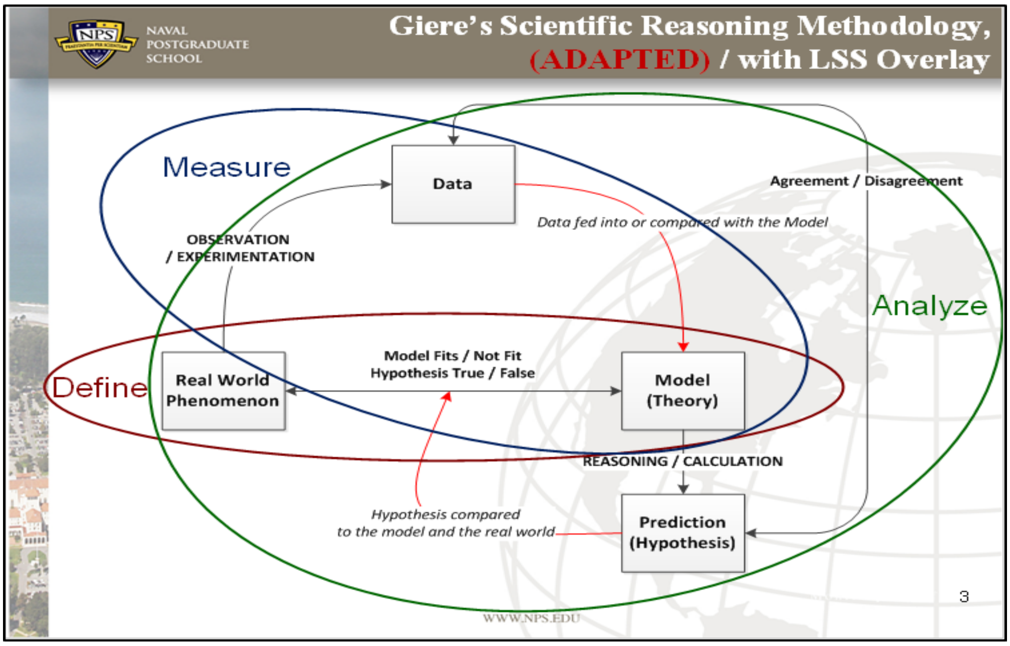


Fig. 4. Methodology (ADAPTED) with LSS Overlay (Overlay Methodology)

Similarly, in the adapted Giere model, if the data and the resulting prediction agree, depicted by the double arrow between data and prediction in Figure 4 above, then the theoretical model is believed to be sound and the hypothesis supported. The prediction results, depicted by the red line, are linked into the double arrow between the real world and the model allowing for comparison between the model and the real world. If the model fits or closely approximates the occurrence in the real world, then the scientist or the LSS team may safely say, again, that their hypothesis is supported. However, if the data and prediction do not agree, the theoretical model's fit comes into question. The theoretical model may contain a pertinent flaw that prevents it from imitating the real world phenomenon in some relevant aspect. This may send the team back to the model and the data to discern what relevant aspect is missing between the model and the real world, or was the calculation or reasoning used incorrect, or was the data somehow corrupted. In each methodology, the scientist and the LSS team will continue to seek agreement between the data and the prediction, which will lead to a determination of goodness of fit between the real environment and the model.

The LSS methodology deliberately identifies the problem area then moves through a process deciding on a metric or set of metrics, then data is collected to analyze those measures. Essentially through these steps a model is developed that will be tested to see if it matches what is happening in the actual environment. As will be seen, once the Define, Measure, and Analyze steps are completed, a model is created that supports the hypothesis of what is occurring in the real world, described here as the As Is model. These LSS phases form the foundational steps of overlay method tying it to the ingredients of scientific reasoning as a basis of explanation, understanding, and formulation.

At this point, the LSS team has a stable "As Is" model, the overlay methodology has proven its worth, they chose the right data to statistically measure and analyze (i.e. derive a sigma), and they can now begin to find what can be improved upon and eventually can be controlled in the two final phases of the LSS process. The overlay model largely serves to provide a stabilized, supported "As Is" hypothesis and to provide important clues for the team to use as they begin to envision a "To Be" process or product. Progressing into the next phases of the LSS methodology, the model scientifically becomes iterative going through all of Giere's ingredients afresh. The Improve and Control phases cover the same elements as Define, Measure, and Analyze but with different data and perhaps a slightly different model. As the team enters the Improve phase, the team begins to visualize the To Be process or product borne out of the As Is analysis.

The Improve phase encompasses the red and blue circles in our overlay methodology, shown in gray above. This is where the team will seek to make improvements to the process through the model. These improvements must be measureable in the model of the real world. Then fresh data will have to be collected after the improvements have been made to learn whether the process or product improvements are having the right effect. Again, the data collected from the actual environment will need to be compared to the model, which would ensure the model adequately fits or does not fit the real world.

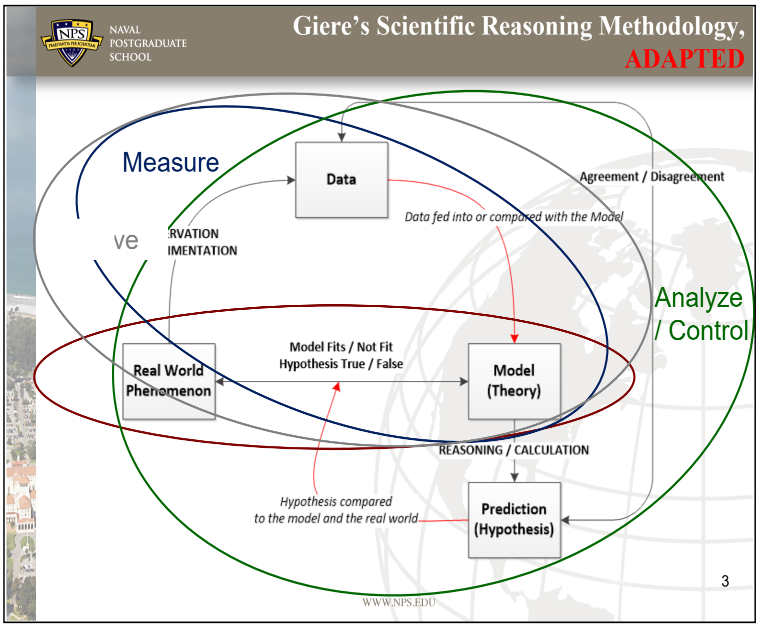


Fig. 5. Overlay Methodology

The LSS Control phase exactly mirrors the Analyze phase of the overlay model, circled in green. The model uses the same statistical calculation with the fresh data and putting the data into the model will determine if it still supports the hypothesis. If it does, then the team focuses on those elements that changed during the improve phase to ensure that those changes become institutionalized, monitored over time, and thereby, controlled. If not, the same procedure would have to be executed to determine if our fresh data was somehow corrupted. Or did the improvements made change the model causing it to no longer fit and reflect the real world. Or were the improvement changes not adequately reflected in the model of the real world process or product. Next an episode will be used to apply the Overlay Methodology to an LSS episode making comparisons to Watson and Crick's scientific episode. This will provide a real world comparison of how the overlay methodology can be operationalized.

4. LEAN SIX SIGMA (LSS) EPISODE

The author had the opportunity to spearhead a LSS project in the Office of the Secretary of Defense (OSD). The project focused on delays in signature package processing either from outside the organization or generated within the organization. Each signature package needed to be routed for signature to the Deputy Assistant Secretary. On average the signature package cycle time took 38 days from beginning to end and did not meet the required due date 72% of the time. This resulted in signature package owners consistently attempting to work outside of the process to get their package completed in a timely manner. This led to the emergence of multiple ad hoc processes that were patently inefficient and unfortunately caused considerable damage to the organizations reputation within the Department of Defense (DoD). This adequately defined the problem at hand.

The author brought together a multi-disciplined team of experts, who had considerable experience with the current As Is process. Next, the team proceeded to document the As Is process. This essentially documented a model of how the process currently worked in the real world of the Pentagon, which had never been done before. At this point, the Define phase was complete, as shown in our overlay methodology in Figure 5 above, depicted by the red circle. Also, the LSS team and Champion for this project believed that a reasonable cycle time for signature packages to traverse the process, from beginning to end, should be 21 days, which became the established benchmark.

This precisely parallels how Jim Watson and Francis Crick, in this case the scientific team, developed their initial model that described Deoxyribonucleic acid (DNA) as a triple polynucleotide chain (Giere, 1979, p. 33). Watson and Crick developed a working model in an attempt to understand what DNA actually looked like in reality. This seems to fit the Define phase of LSS quite nicely. A model was developed by Watson and Crick, which seemed to fit and support their initial hypothesis. But they needed to collect data from real DNA. However, since DNA is infinitesimally small and instrumentation was not quite as sophisticated as it is today, they chose to leverage Crick's theory of x-ray scattering (Giere, 1979, p. 16; Watson, 1998). Gathering data in this LSS episode was much easier; nevertheless, one can see the parallels.

Next, the team entered into the measure phase depicted by the blue circle in the overlay methodology. It became clear from the outset that cycle time of the signature packages was the appropriate measure (i.e. metric) to use, measuring the interval between the arrival of a signature package and its delivery to the tasking organization. The office had collected data for three years on the cycle time data on 3508 signature packages that were processed within the Office between 2006 and 2008. By simply subtracting the signature package arrival date from the delivery date, the team derived the cycle times, in days, for each of the 3508 packages. This constituted a sample of the cycle times of the entire signature package population ever completed by the organization. The data was compared with the model to initially determine whether the model fit the real world phenomenon. At this point, the cycle time measure seemed to fit what was being observed in the real world, which supported the As Is model.

Similarly in the early stages of model development, Jim Watson and Francis Crick presented their DNA model to Rosalind Franklin, a scientific colleague who was engaged in real world observation and experimentation of DNA using the simple x-ray technology of the time. Rosalind Franklin's research found that DNA in the real world contained water molecules at a volume ten times greater than Watson and Crick's current triple chain DNA model could possibly accommodate (Giere, 1979, pp. 33-37; Watson, 1998, pp. 75-87). As such, Watson and Crick's model did not match the data Franklin had gleaned from her x-ray research. This caused Watson and Crick to question the fit of their model. This parallels the LSS episode accurately; the LSS team must feed the data into the model to ascertain if the model fits. In Watson and Crick's case they had to continue their journey to discover DNA, tinkering with their emerging model. In the LSS episode, the team's model was a fit, now they needed to perform the analysis.

Subsequently, the team embarked upon the analyze phase depicted by the green circle above in our overlay methodology. The team used the sample of 3508 signature packages. Calculating the cycle time for each package, using the statistical software employed within DoD. Ultimately, deriving a sample mean cycle time of 38.4 days, with wide variation in the cycle times as shown in Figure 6 below. As expected, the cycle time exceeded the 21 day established benchmark. Most significant was that the sigma score or Z bench derived from the statistical model was a negative 1.89, which in the LSS methodology indicated an extremely poor process. Also, as shown in the top right hand corner of Figure 6, an attempt was made to fit the cycle time data to a statistical distribution. The statistical software could only fit it into a largest extreme value distribution; further, supporting our hypothesis that the process was ineffective and unable to meet the organization's signature package cycle time goal of 21 days.

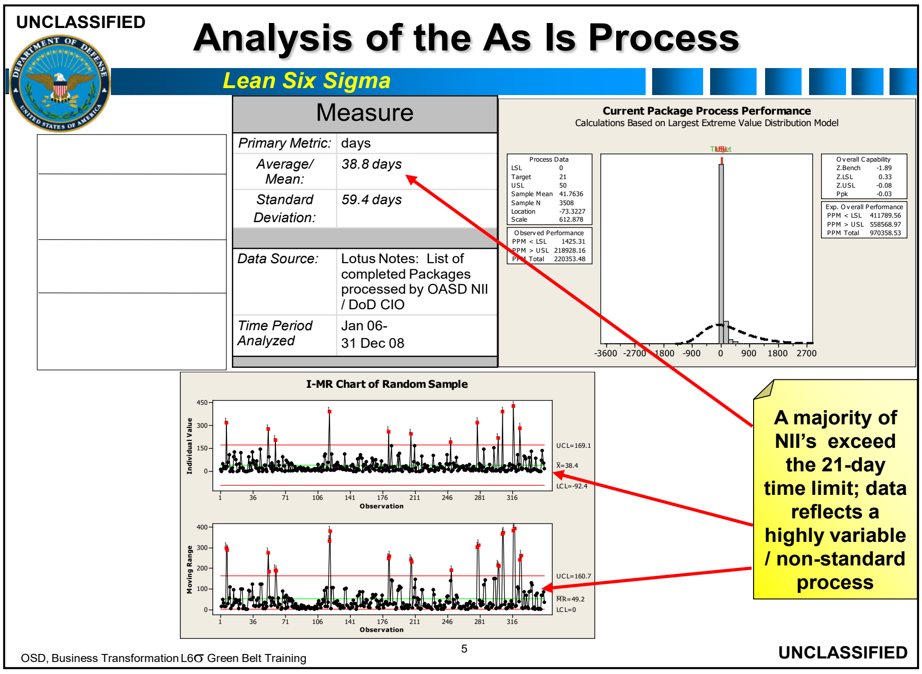


Fig. 6. Analysis of the As Is Process

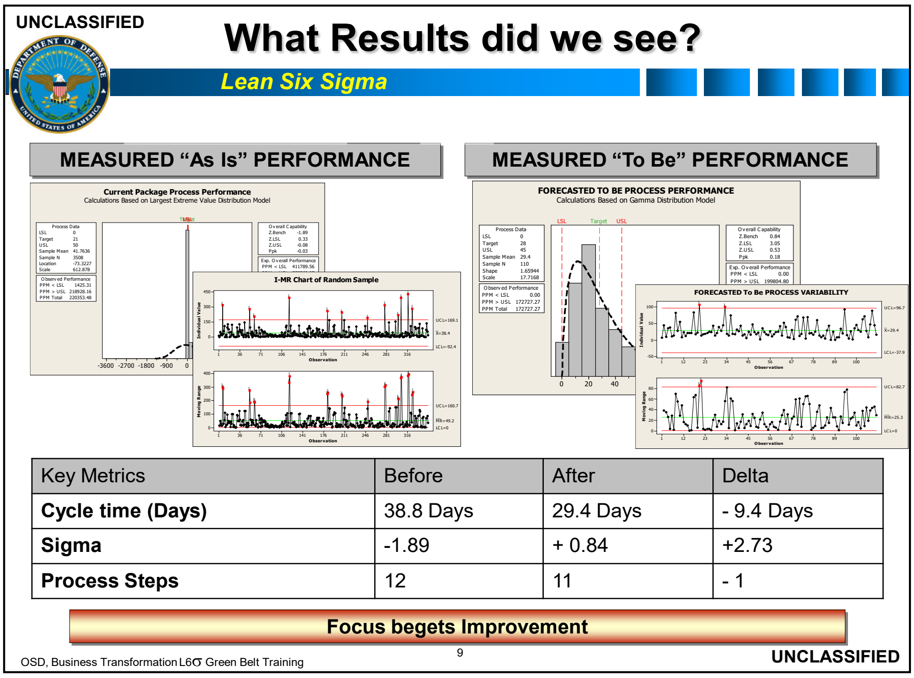
In the same way upon receiving the data from Rosalind Franklin, Watson and Crick had to consider ways to fit their model of DNA. Believing that Franklin's analyzed data was correct; they modified their model to the now widely accepted DNA formulation – the double helix of polynucleotides. This is where the comparison between the scientific and LSS episode ends, because Watson and Crick were seeking the "As Is" state of DNA, they were not in pursuit of some "To Be" model. However, the LSS team continued in an iterative manner through the improve and control phases seeking to achieve the goal of LSS.

Immediately following, the team entered the improvement phase of our overlay methodology, depicted by the gray circle in

Figure 5. The team scrutinized the model to find any wasteful steps that might be eliminated or improved upon; thereby, creating a To Be model. Further, the team explored policy changes that could be employed to make the real world process more efficient. Ultimately, the team was able to eliminate one step, employ a policy standard to establish priorities on certain signature packages, and put a policy in place to prohibit ad hoc workarounds outside of the established process. The team conjectured that making these improvements might sufficiently reduce the cycle time average in our To Be Model. These changes were put into place and immediately the team began gathering fresh data on the signature packages that flowed through the improved process. The Improvement phase leveraged what the team had learned through this LSS methodology, relying heavily on deliberate scientific methods to make decisions.

After collecting data on signature package cycle times over several months, the team was able to compare the fresh data to the To Be model. The data seemed to verify that the model was still performing and was a fit with what was happening in the real world. Thus, the team transitioned to the final phase of Control, which is exactly the same as the analyze phase before, but now using the To Be model.

Thus through statistical calculation, the team was able to Control signature package cycle times and then to compare the prediction with the cycle time data captured from the To Be process. They appeared to be in agreement. Next, the team sought to see if the prediction supported the hypothesis of what was happening in the real world - it did. The current To Be model was coming into control and serving the organizations goals very well. Figure 7 shows a side by side comparison of the statistical calculation results between the As Is and To Be models. Through this LSS methodology the team was able to reduce the process cycle time by 9.4 days, the sigma score improved to a positive .84 - a long way from 6σ but improving in the right direction.



Key Metrics	Before	After	Delta
Cycle time (Days)	38.8 Days	29.4 Days	- 9.4 Days
Sigma	-1.89	+ 0.84	+2.73
Process Steps	12	11	- 1

Fig. 7. Statistical calculations of the performance differences between the As Is and To Be Models

The number of steps had been reduced by one, the variability in the process had been reduced, and the To Be process seemed under better control as shown in the data fitting a gamma statistical distribution. Also, the calculated means between the gamma distribution and the process variability chart matched, again indicating that the process was now stable and under control. Thus, the prediction seemed to support our hypothesis that the process improved through the use of the overlay of LSS atop the Scientific Reasoning methodology discussed earlier and depicted in Figure 5. This supported the hypothesis that LSS was successful due to its foundational roots in scientific reasoning.

5. CONCLUSION

This paper began by introducing LSS as a process/product improvement method. Next, Giere's scientific reasoning methodology was briefly introduced, explored, and adapted; this created adaptive linkages that were used to make comparisons to the LSS methodology. These linkages specifically tied Giere's scientific reasoning ingredients to the LSS phases of Define, Measure, and Analyze. The phases specifically covered all of Giere's ingredients and connections, which he felt was necessary to support a hypothesis or theory. The subsequent steps of the LSS process of Improve and Control were shown to be executed over the scientific ingredients and connections in the proposed overlay model. Essentially, in these last two phases the LSS team executes the scientific reasoning model for a second time, the first time to discover and ensure the fit of the As Is model and the second time to validate the fit of the To Be model. In both cases, this process ensures that the prediction supports the accurate fit of the model - thereby, supporting the hypothesis. Then, leveraging the author's experience, an LSS episode was summarized to support the hypothesis that LSS does leverage the scientific method. By comparing the two throughout the LSS episode in the Define, Measure, and Analyze phases, linkages were made to the discovery of DNA the scientific episode used by Giere. Ultimately, it seems that LSS does employ sturdy scientific reasoning, demonstrating scientific reasoning is indeed the key to the success of LSS.

ENDNOTES

(1) Operationalizations are defeasible rules of the application of a concept such that both the rules and their applications are subject to revision on the basis of new empirical or theoretical developments. As such, to operationalize is to adopt verbal and related practices for the purpose of enabling scientists to do their work (Bogen, 2014).

(2) Law of Parsimony often referred to as Ockham's Razor. The Razor is attributed to an English Franciscan Friar named William of Ockham and is expressed simply as "Don't multiply entities beyond necessity." Or stated another way, when comparing hypothesis that have the same predictive value, the one with the fewest assumptions is better (Spade, 2015).

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