Capacity Improvement of an Advanced Manufacturing using Lean Six Sigma

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Abstract

A lean six sigma has been a useful tool in improving production yield, services, and other business problems however when use on capacity improvement it is not yet defined. This paper is a case study on the implementation of lean six sigma on capacity improvement as an advanced [what? method, process etc.?] in manufacturing plants. This case study capitalizes on the data collected in an advanced manufacturing factory. As such, different methods of data analysis are required for the more given data such as Analytical Hierarchy Process (AHP). AHP was able to list the possible options in improving capacity as well as the impact of each option on the overall weekly output of the production line. As highlighted by AHP, improvement of machine cycle-time is the top option that gives the most impact on increasing weekly output. Root-cause analysis is used to dig deeper into the root cause of each factor identified from AHP. Thorough bottleneck identification using blueprint diagrams is carried out. Through the implementation of the DMAIC method, the capacity improves and the effectiveness of lean six sigma on capacity improvement was verified.

Keywords
Lean, Six Sigma, Capacity, DMAIC, Manufacturing

1. Introduction
Lean Six Sigma is a hybrid performance improvement program that is initiated by modern manufacturing (Albiwi, Antony, Lim & Wiele, 2014). The challenges that modern manufacturing face, pressures them to be competitive and create strategies that would meet customer demand and business profit (Jain & Lyons, 2009). Products with very high requirements require effort to reduce lead times to satisfy customers. The concept of producing more with less has been an obsession with the modern industry due to its ability to minimize business losses. The strength of organizations to manage such characteristics affects the market segment that it can serve (Costa, Filho, Fredendall & Paredes, 2018). Thus, to address such challenges, organizations invested in initiatives that combine Lean and Six Sigma.

Lean thinking emerged with the development of the Toyota Production System. Lean thinking helped Toyota's survival of capital and resource constraints during the post-war recovery (Kurdve et al., 2014). Through that thinking, Lean Manufacturing (LM) was developed and recognized as a management philosophy for world-class manufacturing (Womack et al., 1990). Manufacturing industries considered "lean" as a fundamental framework for enhancing efficiency, reducing waste, and reducing variation (Hopp and Spearman, 2004). Through the process of reducing waste, we optimize by removing operations that do not add value to the procedure. In simple terms, lean creates value by doing more with less (Womack et al., 1990). Lean in assembly lines leads to faster cycle time because of the removal of waste movements. In service industries, it is the identification of waste policies that do not add value to the customer nor the organizations. However, in LSS, consistency in performance is not covered. Thus, the organization often addresses performance variation issues by implying Six Sigma.

A Six Sigma is an initiative for business improvement developed at Motorola by Engineer Bill Smith in the mid-1980s (Snee, 2010). Sigma came from the Greek alphabet used by statisticians to measure variability (Pyzdek & Keller, 2010). Then Six Sigma suggests variability of 3 to 4 defects for every million instances (Linderman, Schroeder, Zaheer & Choo, 2003). One key to the success of the Six Sigma initiative is the step-by-step approach or roadmap.

A lean six sigma focuses on defining, measuring, analysing, improving and controlling (DMAIC) methodology (Antony & Banuelas, 2002) as well as improving the processes by identifying problems and eliminating the root cause

(Timans, Ahaus, van Solingen, Kumar, & Anthony, 2014). The lean Six Sigma is a hybrid combination of both improvement programs that address the cause of poor performance (Snee, 2010). Potential for improvement in Lean Six Sigma has increased since its emergence in the early 2000s.

Several studies have already demonstrated the benefits of Lean Six Sigma in multiple sectors such as service, manufacturing, and sales (Albliwi, Antony, & Lim, 2015; Costa & Godinho Filho, 2016; Godinho Filho, Ganga, & Gunasekaran, 2016; Grima, Marco-Almagro, Santiago, & Tort-Martorell, 2013; Henrique, Rentes, Godinho Filho, & Esposto, 2016; Kumar, Antony, & Tiwari, 2011; Zu, Fredendall, & Douglas, 2008). However, most applications of Lean Six Sigma in manufacturing industries are used for yield improvements. There is a lack of literature on how to implement Lean Six Sigma in production capacity improvement. The capability of Lean Six Sigma in improving production capacity is not known. Furthermore, its application on advance manufacturing in the Philippines is not known. For an organization with increasing product demand, this has been a highly interesting topic that managements are willing to allocate investment.

Thus, the study aims to implement lean six sigma meant to improve on the capacity of an advance manufacturing company. This study will use a case from an advanced electronics manufacturing industry in the Philippines producing motors.

2. Literature Review

3. Methodology

This case study was executed in a motor manufacturing plant located in Calamba, Laguna Philippines where motors are processed from one workstation to next workstation wherein interchangeable parts are assembled in sequence until the final product is finished. Motor production is dictated by the market demand. The intention of this study is to focus on improving the capacity of the advance manufacturing plant to meet the market demand.

3.1. Lean

Lean Methodology is a philosophy and improvement system to transform waste into value (Kim et. al., 2006). Lean has been a potential to transform our mindset about work (Kimball and O'Neil, 2002). Lean categorizes waste into eight types namely; Defects, Overproduction, Waiting, Non-Utilized Talent, Transportation, Inventory, Motion and Extra-Processing. In this case study, we will be focusing on waste that directly affects the capacity of the line. Most of these wastes are Non-Utilized Talent, Waiting, Transportation, Motion and Extra-Processing. These types of waste were identified using process maps that can detect bottleneck actions of the process (Leming-Lee et. al., 2017). For this study, Lean methodology will be incorporated within the analyze phase of the DMAIC.

3.2. Six Sigma

This study exploits using six sigma in an advance electronic manufacturing industry following the DMAIC (Define, Measure, Analyze, Improve and Control) methodology. The different DMAIC phases as well as the corresponding tools used are summarized in Table 1.

Table 1. Summary of DMAIC Tools Used

Phase	Objective	Analysis Tool	Task	Suggested by
Define	Assessment	SMART Objective	Identify sustainability indicators and develop one (or more) sustainability goals that can be linked to the current project	Bjerke et al, 2017
Measure	Assessment	Statistical Process Control	Develop sustainability metrics for the goals included in the Define step	Keller et al., 2019

Analyze	Define significant factors	Analytical Hierarchy Process	Analyze root cause of the problem	Han et al., 2019
		Process Map		
Improve	Define significant factors	Process Map	Perform comparison of sustainability solutions if they might impact the expected project gains negatively	
		Statistical Process Control		Keller et al., 2019
Control	Recommend Improvement	Monitoring Charts	Identify if the Improvement is stable	Tenera et al., 2014

A Six sigma can be summarized into three objectives, namely Assessment, Definition of Significant Factors and Recommendation of Improvement (Saurin and Ferriera, 2009). Define and measure phases assess the current process and set up the basis to guide data collection. Analyze and improve phases identify the significant factors that can be used to create solutions. Lastly, establish the sustainability of the improvement and recommend it to similar situations.

4. Results and Discussion

The result of each phase in DMAIC is elaborated in which the action plans for non-value added activities and other tools are summarized in Table 2.

Table 2. Summary of DMAIC Result

Phase	Objective	Analysis Tool	Result
Define	Assessment	SMART Objective	Declares an objective to increase the weekly capacity from 55,000 units to 60,000 units.
Measure	Assessment	Statistical Process Control	The weekly output process is stable and controllable (Mean=55601, Standard Deviation=1755)
Analyse	Define significant factors	Analytical Hierarchy Process	Identified three top contributors of weekly output capacity namely; Machine related cycle time (32.59%), Man related downtime (21.94%) and Machine related downtime (11.37%).
		Process Map	
Improve	Define significant factors	Process Map	Capacity improvement is significant (p>0.05) from 55,601 to 63,275 weekly output
		Statistical Process Control	
Control	Recommend Improvement	Monitoring Charts	The process is stable and repeatable with no signals from improve phase SPC

The result of DMAIC shows that the improvement items were able to increase the weekly output capacity of the manufacturing line under study. The increased capacity went way beyond the target of 60,000 weekly outputs to a further improvement of 63,275 average weekly outputs. The success of the DMAIC lies on the good assessment of the problem, done in define and measure phases. Measure phase assessed that the process is stable and controllable with no signals detected in SPC. Thus, analyze phase was able to pinpoint the top contributing factors of low output capacity which are Machine related cycle time (32.59%), Man related downtime (21.94%) and Machine related downtime (11.37%). Sustainable solutions were made from the top contributing factors of low output capacity. The details in each phase are discussed further.

4.1. Define Phase

The company profile of the advance manufacturing used in this case study produces motors for its own personal care products. Positive reviews from leading journalists all around the world have improved the demand for these products. According to the advance manufacturing company supply chain 2019, the need for personal care products will increase by 10,000 weekly by 2020. The current performance of the manufacturing line can produce 55,000 units weekly. The current capacity would require additional manufacturing machines to sustain the 2020 market demand of 60,000 units. The advance manufacturing company will be able to meet the market demand without the cost of another manufacturing line. The current demand trend of M9 motors dictates the need for capacity improvement in the manufacturing lines. During the fourth quarter of 2018, the capacity of M9 line 2 was able to sustain an output of 50,000 motor units per week.

Market demand pressures the manufacturing plant to increase the capacity of the assembly line and forces the organization to seek innovative ways for improvement. The company explored a lean six sigma which uses the DMAIC (Define, Measure, Analyze, Improve and Control) methodology to eliminate waste and reduce process variations. The define phase of the case study was introduced as follows:

a. Project Background: The Company under study has been continuously launching new products with a digital motor as a core technology. With the increasing demand for the digital motor, there is a need to improve the capacity of the line.
b. Problem Statement: The Manufacturing line has a high variation of weekly output that draws it back from reaching a peak performance of 60,000 units per week.
c. SMART (Specific, Measurable, Attainable, Repeatable and Time-Bound) Objective: To increase the weekly output of the manufacturing line from 55,000 units weekly to 60,000 units weekly by the 2nd quarter of 2019.
d. Cost Benefit: Increase of motor exportation amounting to 16.4 million US dollars per year.

4.2. Measure Phase

In this phase, the current performance of the process was established through Statistical Process Control (SPC). SPC was able to define the weekly output baseline data and show that the variations of weekly output were all from natural causes. Since there were no signals that indicated unnatural source of variation, the process was controllable. Figure 1 shows the resulting SPC of weekly output.

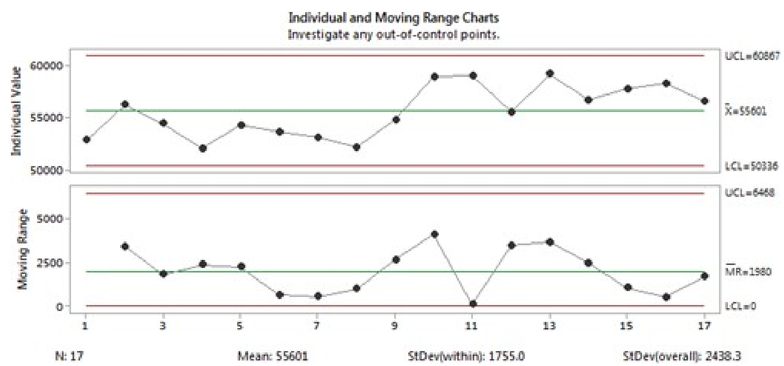

Figure 1. Statistical Process Control of Weekly Output

Figure 1 showed that the performance of the line during the first 17 weeks of 2019 had an average weekly output of 55,000 units. The weekly output count was not enough to sustain the market demand of 60,000 units. The result also showed no unnatural sources of variation which indicated that the process was controllable. The process variation was all from natural sources. Breakdown of factors that affect the low output capacity were identified further in analyze phase.

4.3. Analyze Phase

Top contributing factors were identified under this phase of the DMAIC methodology. Analytical Hierarchy Process (AHP) was able to give weights to each factor. In an advance manufacturing line, there are three main contributors to weekly output, namely Cycle Time, Manpower Skills and Machine Downtime. Cycle time is the speed by which the assembly line can produce a single unit. It can be affected by the design of the machine, the ability of an operator to load parts quickly or the quality of the raw material that reduces over processing. Downtime, on the other hand is the idle time of the machine. The more downtime the assembly gets, the less time it has to create units. Downtime can be affected by the capability of the machine to prevent downtime; the capability of the manpower to recover from downtime and the goodness of raw material to prevent downtime. Lastly, yield affects the number of good unit the assembly line can produce. The weight of each factor was derived based from the 2018 performance of the line. Data source of AHP can be viewed in the appendix. AHP was able to identify the top three contributors of low output capacity as follows: Machine related cycle time, Man related downtime and Machine related downtime. Table 3 show the AHP summary.

Table 3. AHP Calculation on Impact of Each Variable

Issue No	Variable 1	Variable 2	Percent Impact

1	Machine	Cycle Time	32.59%
2	Man	Down Time	21.94%
3	Machine	Down Time	11.37%
4	Material	Yield	9.93%
5	Man	Cycle Time	6.28%
6	Material	Cycle Time	5.30%
7	Machine	Yield	4.87%
8	Material	Down Time	4.51%
9	Man	Yield	3.21%

Based on per cent impact, AHP shows that machine cycle time, workforce downtime, and machine downtime should be the priority. Optimization of machine cycle time is the highest contributor to opportunity losses at 32.59% contribution. Man related downtime and machine related downtime closely follows with a per cent impact of 21.94% and 11.37%, respectively. Because of its high impact on weekly output, machine related cycle time will be the priority in implementing improvement. However, the correlation between the top contributing factors with output capacity should be verified first. If each factor has a significant correlation with output capacity, then we could justify creating sustainable solutions out of the identified factors. Table 4 shows the summary of the correlation analysis of the top contributors to low output capacity identified through AHP.

Table 4. Regression Analysis of Top Issues vs Output

Relationship	P-Value	R	R-squared
Output vs Cycle Time	0.001	-0.91	83.67%
Output vs Man Related Downtime	0.001	-0.99	97.14%
Output vs Machine Related Downtime	0.001	-0.97	94.24%

Regression results show that Machine – Cycle Time has a significant relationship with average output weekly output (P=0.001). A correlation value of -0.91 shows that Machine – Cycle Time goes down; average weekly production tends to increase. Man – Down Time also has a significant relationship with average weekly output (p=0.001). A correlation value of -0.99 shows that as Man related downtime decreases, the average weekly production tends to increase. Lastly, regression results also indicate that Machine – Down Time has a significant relationship with average weekly output (p=0.001). A correlation value of -0.97 describes that as machine-related downtime decrease, the average weekly production tends to increase. Thus, controlling these variables can have a significant effect on the average weekly output. To decrease the impact of each variable, we identify waste present within them. Lean methodology is used to identify the waste from each variable.

The result of lean was able to identify waste present in the top contributing factors of low output capacity. Cycle time is the speed of production from start to end. In a highly automated line waste that can be found that affects cycle time is motion and waiting wastes. Man related downtime is caused by uneven distribution of skilled technicians per shift. Concentration of skilled technicians in a single shift causes non-utilized talent wastes. Lastly, machine related downtime is the inability of the machine to recover itself. Thus, the machine waits for a technician to repair the downtime and resumes production. Waiting waste is highly present as the machine waits for repair.

Issue 1. Cycle Time (Motion and Waiting Waste)
Cycle time is the top contributor of low output capacity identified through AHP. The overall cycle time of an assembly line is dictated by the bottleneck process. The bottleneck process clogs the assembly which limits the overall speed of the line. In this case study, we identify the bottleneck process through the use of process map. Three processes were identified to be the bottlenecks of the assembly, namely Frame Orientation Search, Bobbin to Stator Merging and Stator to Frame Merging. From these bottlenecks, we need to perform the lean methodology and identify wastes. In an advance manufacturing line, motion and waiting waste are very common. Motion waste is often found when robots and cylinders are performing unnecessary movements. When robots move from one position to another, some contain unnecessary paths that can be removed to increase the speed travel. Movement towards unnecessary location is considered motion waste. On the other hand, idle time of robots while waiting for parts is considered as waiting waste.

Issue 2: Manpower Skills Enhancement (Non-utilized Talent Waste)

AHP has identified that man related downtime is the second top contributing factor to weekly output. Man-related downtime is over extension of machine downtime due to lack of manpower capability in repairing the machine. Shift technicians with a better set of skills in mechatronics can minimize downtime compared to shift technicians with lacking mechatronics skills.

A 5-Why analysis was used to verify the need for manpower skills enhancement. As a response, the organization created a program that trains technician and engineers in mechatronics. The organization created a facility with machine setup like the assembly line. Downtime is simulated in this environment and the technicians and engineers' practice until they can minimize the downtime losses. To certify their skill level, the organization assesses their skill level from an examination provided by the local government. The skills enhancement program was able to minimize the occurrence of major downtime. Any downtime exceeding one hour is considered as major downtime. Since the shift technicians are now capable of minimizing downtime losses, fewer major downtime is observed from 16 per month down to 6 per month. The average skills of the manpower for each line significantly increased because of the trainings provided. The manpower needed for each line has been reduced from 7 per shift down to 4 per shift. There is a 42% manpower reduction improvement as a fruit of the skills enhancement

Issue 3: Machine Automated Recovery (Waiting Waste)

Machine Related Downtime was identified through AHP as the 3rd top contributor to weekly output. Downtime due to machine failures is decreasing the availability of the assembly line. Investigation shows that 80% of downtime logs did not exceed 15 mins in duration. Repair of chronic downtime often only needs a press of reset button.

A five why analysis was able to point out the root cause of optimized machine program. The counter action for this issue is to modify the program of the machine. The machines will now be able to recognize chronic downtime and repair it on its own without any assistance from the shift technicians. Availability improved from an average of 82.34% to 93.91% through the machine program modification.

4.4. Improve Phase

In this phase, impact of sustainable solutions identified through analyze phase was measured. Before and after sequences were presented using process map diagrams. The capacity of the assembly line was able to improve from 55,000 units weekly to 63,000 units weekly. Statistical Process Control charts also described that the improved performance of the process is stable and repeatable. The increase in the output means had pushed the weekly capacity of the line to 63,000 units.

The capacity of the advance manufacturing before and after implementing improvements through lean six sigma were proven effective in increasing the production capacity. The increase in production capacity was evident in the weekly output of the line with an increase in statistical mean and the reduction of standard deviation after the implementation of the improvements. Two-sample statistical t-test further verifies that there is a significant increase in weekly capacity before (M=55601) compared to after improvement (M=63245), $t(21) = -8.426$, $p<0.001$.

4.5. Control Phase

Monitoring charts were used to show that the improved process was sustained. The new output trend has been consistently hitting the 60,000 weekly targets. The assembly line normalized at an average weekly output of 63,000 units. The new capacity is the overall result of all improvements taken including cycle time improvement, machine optimization and manpower skills enhancement. Additional certification was used to have a standard on the manpower skills enhancement. Local government certification issued by Technical Education Skill Development Authority (TESDA) Philippines was used to certify trained personnel.

5. Conclusion

This study attempts to bring the lean six sigma (DMAIC) approach to the capacity improvement of advance manufacturing. The DMAIC approach was able to increase the capacity of advanced manufacturing from 50,000 weekly to 60,000 weekly. Specific, measurable and attainable targets were properly established during the define phase. Define phase was also able to establish the scope, timeline and overall projected annual cost savings. Baseline data were taken using statistical process control of weekly output data. Sources of natural and unnatural variations became the subject of investigations. This study also made used of Analytical Hierarchy Process (AHP) in the Analyze phase instead of the conventional Ishikawa (Fishbone) diagram. The abundance of data in an advance manufacturing line enabled the use of AHP. AHP was considered a better alternative to the conventional Ishikawa fishbone diagram since it was able to show weights of the different factors considered. Through AHP, this study was able to prioritize which contributing factors should be tackled, namely machine cycle time, the ability of the workforce to minimize downtime duration, and the strength of the equipment to prevent downtime from occurring. Counter measure for the top contributing factors was implemented and discussed during the improved phase. Resulting improvement impact was plotted with the baseline value obtained in the measure phase, in a before/after I-MR control chart. Overall, this study was able to verify the use of Lean Six Sigma as a means on capacity improvement in an advance manufacturing line. Breakdown of the improvement items presented in improve phase and the effect on weekly output are presented in Figure 2.

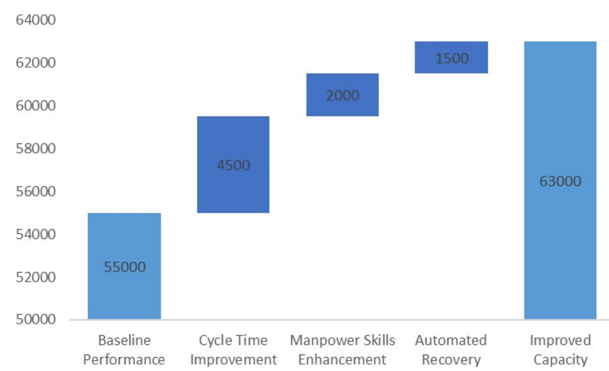

Figure 2. Waterfall Chart of Weekly Output

Figure 2 shows that from a baseline weekly output of 55,000 units, it increased by 4,500 weekly outputs because of cycle time improvements. Manpower skills enhancement further improved the weekly output by 2,000 units. Lastly automated recover of machine improvement added 1,500 weekly outputs from the baseline data. Overall, the manufacturing line became capable of an average weekly output of 63,000 units.

This study can be used as a reference for capacity improvement projects ofother advance manufacturing company as well. Key factors that other organizations should consider in applying the same approach are Data Availability and Process Consistency. The use of AHP on the analysis phase requires abundant data. Other organizations should consider reinforcing their data traceability first before implementing such projects. Manually operated process tends to rely on fishbone diagrams and value-ease matrix. However, value-ease matrixes are subjective and variable weights differ from one perspective to another. Identified top contributors might be misleading and will not solve the actual problem. Other organizations with process consistency would be able to use the same approach with ease. Manufacturing a product with a long lifecycle would make a longer improvement implementation impact. This study highly recommends further verifying the effectiveness of a lean six sigma on manual assembly line. Manual assembly lines may contain other factors that are not identified in this study.

Acknowledgements

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Biographies

Mark Anthony Alata was born on May 8, 1979 in Sta Cruz, Manila. Raised in Manila, he received a B.Sc. degree (Electrical Engineering) from Pamantasan ng Lungsod ng Maynila in 2001, and a M.A.Sc degree (Engineering Management) from Mapua University in 2020. He has worked as a manufacturing engineer at NEC in 2001 and found his passion for manufacturing operations. In 2016, he joined Dyson Electronics Pte. Ltd. - Philippine Branch as a maintenance manager. In his early career as an operation manager, Mark initiated multiple Lean Six Sigma projects that drastically reduced scrap cost of the operation and later became Certified Lean Six Sigma Greenbelt and Certified Lean Six Sigma Blackbelt. Continuous improvement in operation has inspired Mark to pursue studies that would evaluate the use of Lean Six Sigma as a tool for capacity improvement.