American Journal of Industrial Engineering, 2013, Vol. 1, No. 2, 28-35
Available online at http://pubs.sciepub.com/ajie/1/2/4

DOI:10.12691/ajie-1-2-4

Applying Lean Six Sigma for Waste Reduction in a Manufacturing Environment

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Received September 10, 2013; Revised October 17, 2013; Accepted October 18, 2013

Abstract This study was applied in a welding wire manufacturing plant to improve the quality of the manufactured welding wires, reducethe manufacturing waste and increase the yield of the manufacturing process, by applying the Lean Six Sigma (LSS) methodology and waste management. LLS is considered one of the successful approaches in the field of quality improvement and cost reduction. The case study plant working environment was analyzed to isolate the root causes for the waste generation. Remedies and countermeasures were suggested and some were implemented. The study compares the performance of the plant before and after implementation of the proposed solutions for waste reduction. Improvements in yield, waste, Defects Per Million Opportunities (DPMO), and sigma levels were achieved.The LSS methodology was linked to the Analytic Hierarchy Process (AHP) to prioritize the causes of waste. The objective was to use an analytical method in judging the influence of the waste causes on the amount of waste to enrich the methodology effectiveness and facilitate some ease of use in the practical field.

Keywords: *Lean Six Sigma (LSS), Analytic Hierarchy Process (AHP), quality improvement, waste management, welding wire*

Cite This Article: Mohamed K. Hassan, "Applying Lean Six Sigma for Waste Reduction in a Manufacturing Environment." *American Journal of Industrial Engineering* 1, no. 2 (2013): 28-35. doi: 10.12691/ajie-1-2-4.

1. Introduction

LeanSix Sigma is a well-known methodology for quality and waste improvement. The Lean Six Sigma methodology is characterized by the DMAIC phases. Motorola Company recognized that there was a pattern of improvement that could naturally be divided into the five phases of problem solving, usually referred to by the acronym DMAIC, which stands for Define-Measure-Analyze-Improve-Control [1]. DMAIC forms the five major phases of any Six Sigma project. Lean Six Sigma is a disciplined, data-driven methodology used to eliminate/reduce the process hence the product defects and waste. To achieve Six Sigma qualities, a process must produce no more than 3.4 defects per million opportunities. Researchers such as [2] even suggested a new control chart for attributes data to represent the defects per billion opportunities (DPBO). Six Sigma's basic value proposition is that principles for process improvement, statistical methods, customer focus, attention to processes, and management system focusing on high-return improvement projects result in continuous improvement and significant financial gains. With the implementation of Six Sigma, it is possible to determine the key factors affecting a manufacturing process, identify the optimum levels or tolerances and improvement opportunities [3]. In the current work the DMAIC process of the Lean Six Sigma was followed to achieve quality and productivity improvement in awelding wire company. The company manufactures welding wires in a wide range. Many opportunities for improvement were recognized during the investigation stage early in the beginning of the Define stage of the Lean Six Sigma methodology. These opportunities drawn the attention for multiple areas for improvement and emphasized the need for research leading to improvement by applying methodologies such as the Lean Six Sigma. The main problem was to decide at which stage of the manufacturing process, the methodology implementation had to start. The contribution of the current research proved that the Lean Six Sigma methodology is a suitable approach to be followed to reduce the waste in the welding wire manufacturing process. Waste reduction is a crucial subject in the quality and productivity improvement of such manufacturing process. Hence, it was considered as the main objective of the current work.

2. Concepts

The fast changing economic conditions such as the severe global competition, declining profit margin, customer demand for high quality product, product variety and the need to reduce lead–time have major impact on manufacturing industries. To respond to these needs various industrial engineering and quality management strategies such as ISO 9000, Total Quality Management, Kaizen engineering, Just–in–time manufacturing, Enterprise Resource Planning, Business Process Reengineering and Lean Management have been developed. A new paradigm in this area of manufacturing strategies is Six Sigma. The Six Sigma approach has been increasingly adopted worldwide in the manufacturing sector in order to enhance productivity and quality performance and to make the process robust to quality variations [4].

2.1. Quality Management and Quality Improvement

Reference [5] mentioned that quality is defined as the fitness for use or purpose at the most economical level. It is an integral part of the process of design, manufacture and assembly. It can be assured by having effective procedures and controls at various stages. In manufacturing industries, to overcome the competition problem and to retain the share of the market, it is necessary to constantly improve the quality of the product without the increase in the price. The price is influenced by the cost of production, which in turn is influenced by waste, rework, rejection and downgrading rates. Attention to quality assurance can reduce the process waste, which results in a quality production and company's growth and profitability.

2.2. Six Sigma

Reference [6] defined Six Sigma as a methodology for quality improvement. The Six Sigma concept was introduced in the early 80's by Motorola due to two reasons. First reason was the nature of mass production and second reason was the threat of the Japanese products in the American market.

It is known that a process working at 3 sigma level introduces 2600 defect per million which is not acceptable in many situations like the production of the printed circuit boards. The implementation of Six Sigma is always done using DMAIC approach [7,8,9]. In some of the above mentioned references, the five letters abbreviations are simply explained as follows;

- **D**: Define; what problem needs to be solved?
- **M**: Measure, What is the capability of the process?
- **A**: Analysis, When and where do defects occur?
- **I**: Improve, How the process capability can be improved?
- **C**: Control, What control can be put in place to sustain the gain?

An implementation Model for Six Sigma was applied. The modelimplies a top down approach were strategic decisions based on the market/customer analysis must be taken by the management [10]. The model calls also for tactical decisions implying bottom up approach, where engineers or technicians are primarily involved in the decision making process in terms of the design of detailed plans to form low-level improvement teams, and the implementation, documentation, and revision of the plans' executions.

2.3. Statistical Significance of Six Sigma

In statistics, sigma denotes the standard deviation of a set of data. It provides a measure of variability which indicates how all data points in a statistical distribution vary from the mean (average) value. For the original curve of standard normal distribution, the 3σ process with no shift (in the short term) leads to the area under the curve to be 0.99865 of the total population and the corresponding DPMO of 2700 [11,12]. The Six Sigma approach assumes a long-term process mean shift of $\pm$ 1.5σ, which leads to an area under the curve of 0.93319 and a corresponding DPMO of 66800. For the original curve of standard normal distribution, the $\pm 6\sigma$ process with no shift (in the short term) leads to the area under the curve to be 0.9999999 and the corresponding DPMO of 0.002. The Six Sigma approach assumed a long term process to be within $\pm$ 1.5σ. This leads to an area under the curve of 0.9999966 and the corresponding DPMO of 3.4 [13].

2.4. Total Quality Management

Reference [4] described in that, within the last two decades, Total Quality Management (TQM) has evolved as a strategic approach in most of the manufacturing and service organizations to respond to the challenges posed by the competitive business world. Today TQM has become a comprehensive management strategy which is built on foundation of continuous improvement & organization wide involvement, with core focus on quality. TQM is a process of embedding quality awareness and actions at every step of production or service while targeting the end customer. TQM has culminated Six Sigma which targets 99.99927% defect free manufacturing. Six Sigma grew out of the concept of TQM [14,15]. Similarities and differences between TQM, Six Sigma, and Lean are discussed in [16].

2.5. Success Factors for Six Sigma Implementation

The critical success factors for any Six Sigma project implementation as mentioned inreference [17] and some of them were discussed by reference [18] include the following points which reflect the link between Six Sigma implementation and engineering management tools:

- Management involvement and commitment.
- Culture change.
- Communications.
- Organization infrastructure.
- Training as a parallel learning structure [19].
- Linking Six Sigma to business strategy, customer, suppliers and human resources.
- Project Management skills and how it is linked to quality management [20].
- Understanding tools and techniques within Six Sigma environment.
- Project prioritization and tools.

2.6. Lean Management

The concept of 'Lean' was first introduced in reference [21] in order to describe the working philosophy and practices of the Japanese vehicle manufacturers and in particular the Toyota Production System (TPS) [22]. More specifically, it was observed that the overall philosophy provided a focused approach for continuous process improvement and the targeting of a variety of tools and methods to bring about such improvements. Effectively, the philosophy involves eliminating different types of process or actually thinking waste.

It is important to distinguish between those considering Lean from a philosophical perspective related to guiding principles or overarching goals, and those analyzing the concept from a practical perspective as a set of management practices, tools, or techniques that can be observed directly and involve eliminating waste, whether it be time, materials, efficiency or processes. In other words, it's how to eliminate the wasteful way of thinking by removing the non-value added processes from the work flow. It also means figuratively tightening the belt in pursuit of increased productivity gains that will increase a company's ability to compete more successfully [23].

2.7. Types of Wastes

Any operation in a process which does not add value to the customer is considered 'waste'. Lean manufacturing is a work environment management philosophy focusing on the reduction or elimination of the following seven types of waste [24]:

1. *Over-production:* Product made for no specific customer or the development of a product, a process or a manufacturing facility for no added value
2. *Waiting time:* While people, equipment or product is waiting it is not adding any value to customer
3. *Transportation:* Unnecessary product movement to several locations. If the product is in motion and not being processed then no added value to the customer
4. *Over Processing:* When a particular process step does not add value to the product
5. *Inventory:* Unnecessary storage of products, intermediates or raw materials is considered waste of money
6. *Motion:* Excessive movement of data, information or the people who operate the manufacturing facility is wasteful. While they are in motion they cannot support the processing of the product
7. *Defects:* Errors during the process either requiring re-work or waste of the product.

2.8. LeanSix Sigma (LSS) Model

Both Lean and Six Sigma are key business process strategies which may be employed by companies to enhance their manufacturing performance[25]. Integrated LeanSix Sigma (LSS) model for manufacturing industry is illustrated in Figure 1, which is similar to the regular Six Sigma train of thoughts.

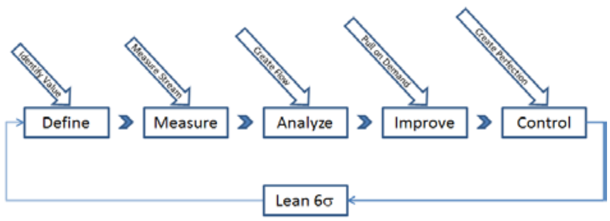

Figure 1. Integrated Lean Six Sigma (LSS) modelapproach

3. Waste Reduction as a Quality Improvement Application

While efforts to reduce waste, defective products and inventories have increased, improved productivity, customer satisfaction, and superior quality have become increasingly important[26]. Manufacturing waste reduction and quality improvement implementation were discussed in reference [27], where the overall process of manufacturing waste reduction is described. The key elements introduced are, being a top management leadership, measurement participation through quality improvement teams, and communications. The implementation was accomplished in two phases such that:

Phase I

- Define organization
- Define and document methods
- Establish measurements
- Present/Market initiative to manufacturing plants

Phase II

- Audit plant methods and progress
- Review/audit specific manufacturing processes
- Address conflicts, opportunities, etc. at the company level
- Coordinate design review efforts with product engineering
- Interact with and assist plant teams
- Provide systems support
- Refine methodologies, reports, etc.
- Report to the company steering committee
- Facilitate spreading of the gains

4. Prioritization of Alternatives Using Analytic Hierarchy Process

In the current work, one of the aims is the use of industrial engineering tools to enrich the Six Sigma methodology. This was demonstrated in using the analytic hierarchy process (AHP) method in the prioritization of the causes leading to the waste generation in the welding wire manufacturing process. The AHP method was originally developed by Thomas L. Saaty in the late 70's of the last century [28,29]. Since that time, AHP is widely used for multi-criteria decision-making and has successfully been applied to many practical decision-making problems. In the AHP, the alternatives are structured hierarchically at different levels, each level consisting of a finite number of elements that may contribute to the decision making process. The relative importance of the decision elements (i.e. the weights of the criteria and the scores of the alternatives) is assessed indirectly from pair-wise comparison judgments as input to the model. Reference [30] stated that, "The most effective way to rationalize judgments is to take a pair of elements and compare them on a single property without concern for other properties or other factors".

5. Industry Application

5.1. Define Phase of the LSS Project

The welding wire manufacturing process is composed mainly of the following steps. The wire coils come from the supplier, pass through a descaling process to remove the rust, go through drawing to the required diameter then cut to the desired length. The flux is prepared from some powder chemicals that are combined with sodium and potassium silicate to form the flux paste. The cut wire is covered by the flux paste during the extrusion process. The extruded wires are then dried, inspected for conformance then packed. SIPOC is an acronym standing for supplier, input, process, output, and customer. It refers to the technique of analyzing a process relative to these parameters to fully understand their impacts. A SIPOC diagram for the welding wire manufacturing process is given in Table 1.

Table 1. SIPOC Diagram for the Welding Wire Manufacturing Process

Supplier	Input	Process	Output	Customer
Steel Wire Supplier	Steel Coils	Drawing & Cutting	Cut Wire	Drawing Dept.
Powder & Silicate Supplier	Powder, Sodium & Potassium	Flux Preparation	Flux Paste	Preparation Dept.
Drawing & Flux Preparation Dept.	Cut Wire & Flux	Extrusion & Drying	Welding Wire	Extrusion Dept.
Extrusion Dept.	Welding Wire	Packing	Packed Wire	Packing then End User
Start Boundary: Raw Materials from Suppliers	→			**End Boundary**: Final Product to End User

In the first phase –the Define phase- of the current Six Sigma (DMAIC) process there were four main steps implemented as follows:

(1) Investigation of the Company Processes & Work Environment
(2) Drafting the Supplier, Input, Process, Output, and Customer (SIPOC) Diagram.
(3) Collecting Preliminary Data
(4) Writing Problem Definition Statement

As a part of the define phase of the Lean Six Sigma methodology, historical preliminary data was collected to define the size and nature of the existing problems. The records of the waste in the previous four years from 2009 to 2012were collected as given in Table 2. The %6.90 waste in the year 2009 was taken as the base year to study and compare the subsequent years' improvement efforts done by the factory towards a target waste of less than or equal 2% of the total input material. As shown on the table, the company had good effort of self-improvement based on strict follow up of the manufacturing processes that started in 2009, which shows in the reduction of the percentage waste. The percentage wasted ropped to %6.14 in 2007 (a difference of %0.76 from previous year) as the follow up program was initiating. The improvement went through its peak to reach %4.90 waste in 2011 (a difference of %1.24 from previous year) as the efforts gained the momentum, then went down in 2012 to be at %4.25 (a difference of %0.65 from previous year).The reason for the decrease in the waste improvement ratio is due to the limited capability of the traditional work management and follow up techniques to reduce the waste behind certain limits. Given the waste ratio achieved in year 2012 which was 4.25%, and the target ratio of %2, which means a reduction in waste of %2.25 was required; then a powerful methodical technique such as Lean Six Sigma was needed to be implemented to enable this high goal of waste reduction.

Table 2. Waste in Years 2009-2012

Year	Production (tons)	%Waste
2009	8024	6.90
2010	5346	6.14
2011	6605	4.90
2012	7471	4.25

5.2. Measure Phase

The second phase of the DMAIC process is the Measure phase, performed in four main steps:

(1) Process Mapping
(2) Data Collection
(3) Sigma level calculations
(4) Down Time Measurements

In order to have a detailed understanding of the different processes in the welding wire manufacturing process and their relationships, the process map as one of the tools of LSS was used.

The process map highlights the different areas where the waste may be generated. Studying the process elements revealed that there are three main types of waste namely; defective incoming wire (referred to as 'wire' in this context), defective flux paste (referred to as paste), and defective welding wire or electrodes. The breakdown of the different waste types generated in year 2012, which was taken as the base year for improvement.

In this phase the criticality of each type of waste shall be analyzed. A Pareto chart as one of the tools of Lean Six Sigma methodology was used to display the criticality of each waste type as shown in Figure 2.

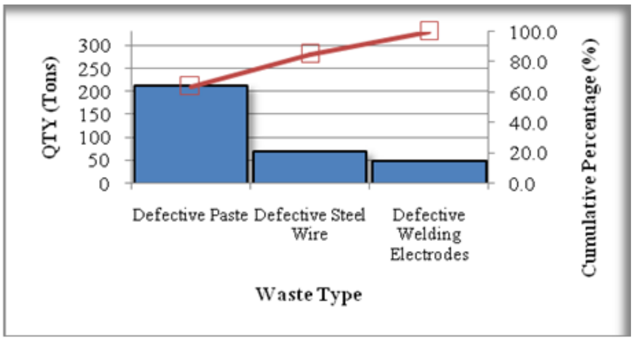

Figure 2. Pareto diagram displaying the waste type criticality

According to the collected data through 2012, the annual waste ratio was 4.25% of total annual input material, and the calculated yield was 95.75%. The yield calculations are displayed below.

5.2.1. Sigma Level Calculations

To judge the process capability on producing defect free products, one must properly define and quantify the process defects per unit (DPU), and the defects per million opportunities (DPMO). Data was collected to calculate the existing and target yield values and the sigma levels as follows:

$$Yield = 1 - Deffective\ Ratio \tag{1}$$

To estimate the sigma level of the process, given that the normal distribution is adequate model for the process:

$$\sigma\ level = \Phi^{-1}(Y) + s \qquad (2)$$

$$Y = Yield / 100$$

$\Phi^{-1}(Y)$ is the inverse cumulative function of normal distribution,

s, is the shift of the mean and is assumed to be 1.5 the standard deviation on the long run. Which means the process is assumed to have a shift in the mean either to the right or to the left of ± 1.5 σ on the long run of the process life. And all the sigma level and DPMO calculations are based on this assumption. Therefore, the calculations are computed taking into account this maximum sigma shaft as follows:

$$DPU = 1 - Y \qquad (3)$$

$$DPMO = DPU * 10^6 \qquad (4)$$

The Yield data collected from the company in 2012 are used to calculate the sigma level as follows:

In 2012 the defective ratio was %4.25, then

Yield = 1-deffective ration = 1-4.25 = 95.75%

Therefore, Y = 0.9575

Substituting in equation (2), then,

$$\sigma_{level} = \Phi^{-1}(.9575) + 1.5 = 1.722 + 1.5 = 3.22$$

$$DPU = 1 - Y = 1 - 0.9575 = 0.0425$$

$$DPMO = DPU * 10^6 = 0.0425 * 10^6 = 42500$$

However, as indicated before, the company looks forward to achieve a target waste ratio of %2. This target is transformed to target Sigma level as follows:

$$DPU = 0.02, \text{ So, } Yield = 1 - DPU = 1 - 0.02 = 0.98$$

$$\text{Target } \sigma_{level} = \Phi^{-1}(.98) + 1.5 = 2.05375 + 1.5 = 3.55375$$

5.3. Analyze Phase

The third phase of the DMAIC process includes the definition of the main causes of the waste and a root cause analysis using one of the tools such as the fishbone diagram prioritizing the importance or criticality of each cause using a tool such as the Pareto chart. In this work a judgmental model, known as the Analytical Hierarchy Process (AHP), was also applied to prioritize the criticality of the different causes of waste.The fishbone diagram was used as one of the effective tools for root cause and sub-cause analysis as illustrated in Figure 3.

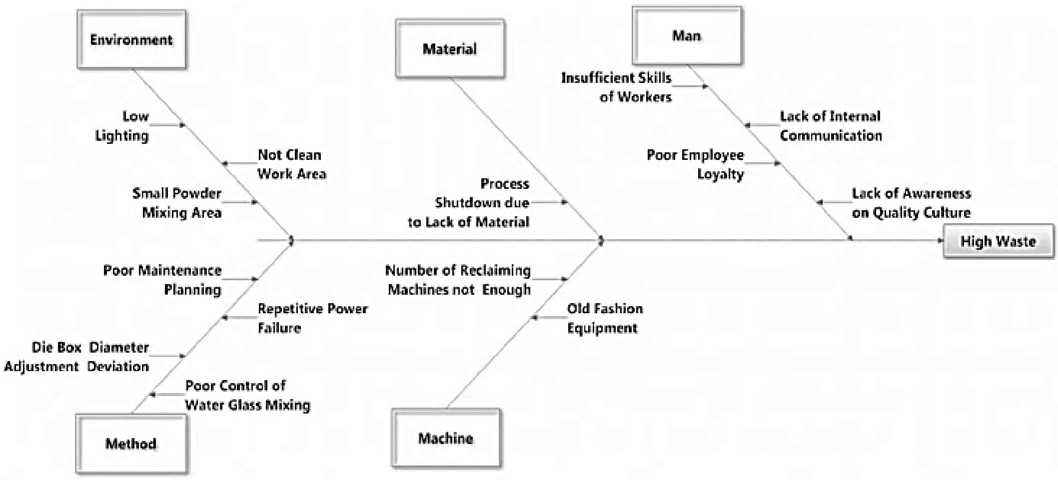

Figure 3. Fishbone diagram offactors leading to waste

Table 3. AHP Inputs from First Decision Maker

Row	Factor I	Evaluation																	Factor II
1	Man	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Material
2	Man	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment
3	Man	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Machine
4	Man	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Method
5	Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment
6	Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Machine
7	Material	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Method
8	Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Machine
9	Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Method
10	Machine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Method

5.3.1. Prioritization for the Main Causes of Waste

This section illustrates the use of the Analytic Hierarchy Process (AHP), which was used to prioritize the main causes of waste generation. As shown on the fish bone diagram the main factors that need to be ranked in regards to their effect on the waste generation are, Man, Material, Machine, Method and Environment. These factors are to be ranked using the AHP method as shown on Table 3. A group of five decision makers from the company key persons contributed to this stage of AHP, which is the pair-wise comparison between every two factors.

The AHP scale is divided from 1 to 9 for 1 being the lowest influence and 9 being the highest influence. The influence of one factor compared to the influence of the other factors on the waste generation is judges. For example in row 1, when comparing the influence of the Man to the influence of the Material on the waste generation, this evaluator sees that the Material has a higher influence than the Manas he graded on the right scale and on the relative scale gives it 3 out of 9. In case of row 2 comparing the Man's influence to the Environment's influence, this evaluator sees that the Man has a higher influence than the Environment as he graded on the left scale with a weight of 3 out of 9.

The main causes were branched to sub-causes as shown on the fish-bone diagram in Figure 3. Similarly, using the AHP method, the weights of the sub-causes were calculated as listed on Table 4. Refer to Saaty, 1990 for a complete explanation of the AHP method and the calculations of the relative weights for the sub-causes.

Table 4. Calculated Weights of the Main and Sub-Causes

Main Cause	Weight of main cause	Sub-Cause	Normalized Weight of Sub-Cause
Man	0.104	Insufficient skills of workers	0.015
		Lack of internal communication	0.056
		Lack of awareness of quality culture	0.008
		Poor employee loyalty	0.027
Material	0.219	Process shutdown due to lack of raw materials	0.222
Environ-ment	0.090	Low lighting	0.016
		Not clean work area	0.057
		Small powder mixing area	0.007
Machine	0.310	Old fashion equipment	0.240
		Number of reclaiming machines not sufficient	0.073
		Die box diameter adjustment deviation	0.028
Method	0.277	Poor control of water glass mixing	0.119
		Repetitive power failure	0.029
		Poor maintenance planning	0.104
	1.000	SUM	1.000

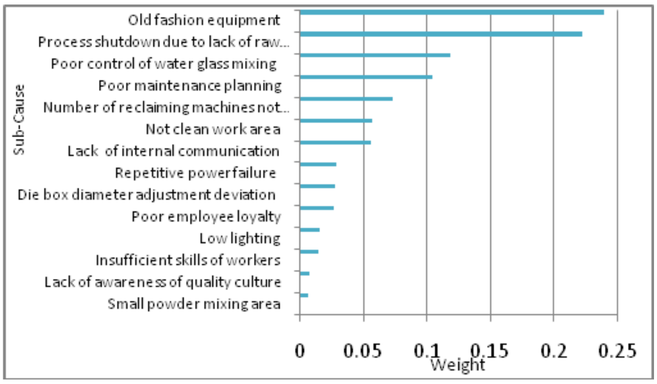

Figure 4. Ranking of the sub-causes weights

Figure 4 shows the ranking of the fourteen sub-causes, the aggregations of the decision-making group pair-wise comparisons are illustrated with the normalized weights. The chart shows a descending order of the sub-causes organized by their normalized weight. From this chart, we see that the old fashion equipment had the highest effect on the waste generation, then the process shutdown due to lack of raw material and so on till reaching the factor that had the lowest effect on the waste generation, which is the small powder mixing area.

The 80-20 rule was used to recognize the sub-causes that have the most influence on waste generation using the Pareto chart. The rule showed that, there are six sub-causes that account for %80 of the waste generation as follows:

(1) Old fashion equipment
(2) Process shutdown due to lack of raw materials
(3) Poor control of water glass mixing
(4) Poor maintenance planning
(5) Number of reclaiming machines not sufficient
(6) Not clean working area

These causes were considered in the improve phase of the Lean Six Sigma process to be addressed for possible improvement according to the available company resources.

5.4. Improve Phase

The improvement actions that were accomplished by the company were:

(1) Monthly waste monitoring and reporting to be implemented for the purpose of keeping the waste below 2 % as per design specifications.
(2) A new control panel was installed for the drawing and cutting machines instead of the previous panel of poor condition as a countermeasure for the old fashion equipment.
(3) A contract with a new supplier for steel wire was established and materials were received from that supplier as a countermeasure for the lack of raw material cause.
(4) The glass mixing machine was replaced by a new one with accurate control system to have a highly reliable measuring and mixing system as a countermeasure for the poor control of water glass mixing.
(5) Complete maintenance program was implemented to the drawing and cutting machines, the two main machines in the production line. This came as a countermeasure for the poor maintenance planning problem.

(6) One new reclaiming machine was added to the existing one to increase the reclaiming capacity and overcome the reclaiming bottleneck as a countermeasure for the insufficient number of reclaiming machines.
(7) As a countermeasure for the not clean working area problem, the cleaning process of the work area was promoted by implementing a daily schedule of cleaning with a check list containing the name of the responsible worker, the area and the machines to be cleaned as well where his signature.
(8) Restricted instructions for engineers to avoid having any unpacked products were also implemented to avoid generating more waste due to bad storage.

The results indicated that, for the year of 2012 the calculated yield was 95.75%, from this yield, the sigma level was calculated and found to be 3.22 corresponding to DPMO of 42,500. Using the company's target of 2% waste, the target sigma level was calculated to be 3.55 leading to DPMO of 20,000 and per design yield of 98% as mentioned earlier. After applying the LSS methodology the yield after the improvement efforts reached 98.24% corresponding to a sigma level of 3.6 and DPMO of 17,600.

5.5. Control Phase

For the sustainability purpose and to achieve improved performance, a control plan was designed and communicated for all company activities related to the objective of the study. Part of the control plan is shown in Table 5.

Table 5. Control Plan Communicated for the Company Staff

Accomplished Recommendation	Planned Actions for Control	Frequency	Responsibility
A contract with a new supplier for steel wire was established	-Evaluation for all suppliers	-Three months	-Purchasing Department
Mixing machine replaced by a new one with a more reliable counter.	-Predictive and Preventive maintenance as per manuals	-Weekly	-Maintenance Department
Complete maintenance was implemented to the drawing and cutting machine	-Predictive and Preventive maintenance as per manuals	-Weekly	-Maintenance Department
Cleaning process of the work space	-Set schedule forcleaning with a checklist and signature	-Daily	-Production Department
Instructions for engineers to avoid having any unpacked products	-Ensure that there is no unpacked products	-Daily	-Production Department

6. Conclusions

The five phases of the LSS methodology DMAIC process were implemented in the welding wire manufacturing company. The tools of the LSS methodology enriched the efforts towards waste reduction. Linking AHP for prioritizing the influence of causes on the waste generation and to determine their countermeasures to cure the root causes of the problems. As one of the industrial engineering tools, AHP integration was also a contribution of the current work to increase the effectiveness of such a methodology of LSS. The AHP questionnaires were conducted by the welding wire manufacturing company key persons and their feedback was analyzed to categorize the priorities of the causes of waste. Cause and effect study using the fishbone diagram was used to address the main causes of the waste in the welding wire manufacturing. The 80/20 rule of the Pareto analysis was used to identify the most important causes of waste to deal with.The objective of the company's management was to reduce the waste ratio to be below 4%, which could not be achieved without following a systematic methodology like LeanSix Sigma. LSS was proved to be a valuable tool in the case of systematic waste reduction objectives. Integrating LSS with other statistical tools could extend its effectiveness and sustain the improvements obtained as in the case of applying the quality plan tool.

References

[1] George, M. L., Rowlands, D. and Kastle, B. *What is Lean Six Sigma*, McGraw-Hill, New York, 2004.

[2] Daryl, S., Beyond Six Sigma – A Control Chart for Tracking Defects per Billion Opportunities (dpbo), *International Journal of Industrial Engineering*: *Theory, Applications and Practice*, 16 (3): 227-233,2009.

[3] Adan, V., Jaime, S., Salvador, N. and Berenice, G. N. Implementation of Six Sigma in a Manufacturing Process: A Case Study, *International Journal of Industrial Engineering: Theory, Applications and Practice*, 16 (3): 171-181,2009.

[4] Desai, T.N. and Shrivastava, R. L., Six Sigma A New Direction to Quality and Productivity Management, *Proceedings of the World Congress on Engineering and Computer Science*, San Francisco, USA, October 22-24, 2008.

[5] Vijayaram, T. R., Sulaiman, S., Hamouda, A. M. and Ahmad, M. H., Foundry quality control aspects and prospects to reduce scrap rework and rejection in metal casting manufacturing industries, *Journal of Materials Processing Technology*, 178: 39-43, 2006.

[6] Raisinghani, M. S., Six Sigma: concepts, tools, and applications, *Industrial Management & Data Systems*, 105 (4): 491-505, 2005.

[7] Kaushik, P., Khanduja, D., "DM make up water reduction in thermal power plants using Six Sigma DMAIC methodology", *Journal of Scientific and Industrial Research*, Vol. 67 No.1, pp.36-42, 2008.

[8] Thomas, A., Barton, R. and Byard, P., Methodology and Theory Developing a Six Sigma maintenance model, *Journal of Quality in Maintenance Engineering*, 14 (3): 262-271, 2008.

[9] Kumar, S. and Sosnoski, M., Reflective Practice Using DMAIC Six Sigma to systematically improve shop floor production quality and costs, *International Journal of Productivity and Performance Management*, 58 (3): 254-273, 2009.

[10] Chakravorty, S., Six Sigma programs: An implementation model, *Int. J. Production Economics*, 119: 1-16, 2009.

[11] Arthur, J., *Lean Six Sigma Demystified*. McGraw-Hill, United States, 2007.

[12] Behara, R.S., Fontenot, G.F. and Gresham, A., Customer satisfaction measurement and analysis using Six Sigma, *International Journal of Quality & Reliability Management*, 12 (3): 9-18, 1995.

[13] Pyzdek, T., *The Six Sigma Handbook Revised and Expanded*. McGraw-Hill, United States, 2003.

[14] Black, k. and Revere, l., Six Sigma arises from the ashes of TQM with a twist, *International Journal of Health Care Quality Assurance*, 19 (3): 259-266, 2006.

[15] Kreisler.K., Buch, and Tolentino A., Employee expectancies for Six Sigma success, *Leadership & Organization Development Journal*, 27 (1): 28-37, 2006.

[16] Andersson, R., Eriksson, H. and Torstensson, H., Similarities and differences between TQM, Six Sigma and Lean, *The TQM Magazine*, 18 (3): 282-296, 2006.

[17] Cornado, R.B. and Antony, J., Critical success factors for the successful implementation of Six Sigma project in organization, *The TQM Magazine*, 14 (2): 92-99, 2002.

[18] Kwaka, Y. H. and Anbaribi, F. T., Benefits, obstacles, and future of Six Sigma approach, *Technovation*, 26:708-715, 2006.

[19] Buch, K. and Tolentino, A., Employee perceptions of the rewards associated with Six Sigma, *Journal of Organizational Change Management*, 19 (3): 356-364, 2006.

[20] Parast, M.M., The effect of Six Sigma projects on innovation and firm performance, *International Journal of Project Management*, 29 (1): pp. 45-55, 2011.

[21] Womack, J.P., Jones, D.T. and Roos, D., *The Machine that Changed the World*, Rawson Associates, New York, NY, 1990.

[22] Hicks, B.J., Lean information management: Understanding and eliminating waste, *International Journal of Information Management*, 27: 233-249, 2007.

[23] Rathje, M. S., Boyle, T. A. and Deflorin, P., *Lean take two Reflections from the second attempt at Lean implementation*, Business Horizons, 52: 79-88, 2009.

[24] Melton, T., The Benefits of Lean Manufacturing What Lean Thinking has to Offer the Process Industries, *Chemical Engineering Research and Design*, 83 (A6): 662-673, 2005.

[25] Thomas, A., Barton, R. and Okafor, C. C., Applying Lean Six Sigma in a small engineering company a model for change, *Journal of Manufacturing Technology Management*, 20 (1): 113-129, 2009.

[26] Katok, E., Serrander, T. and Wennstrom, M., Throughput improvement and scrap reduction in aluminum can manufacturing, *Production and Inventory Management Journal*, First Quarter , pp. 36-42, 1999.

[27] Vokurka, R. J. and Davis, R.A., Quality Improvement Implementation: A case study in manufacturing scrap reduction, *Production and Inventory Management Journal*; Third Quarter, pp. 63-68, 1996.

[28] Saaty, T. L., Applications of Analytical Hierarchies, *Mathematics and Computers in Simulation*, 21: 1-20, 1979.

[29] Saaty, T. L., Multi-criteria Decision Making: *The Analytic Hierarchy Process*, McGraw-Hill, New York, 1980.

[30] Saaty, T. L., How to make a decision: The Analytic Hierarchy Process, *European Journal of Operational Research*, 48: 9-26, 1990.