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SIX SIGMA APPLICATION IN MANUFACTURING SPECIAL PROCESS: A CASE STUDY ON RESISTANCE WELDING

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ABSTRACT

Six sigma is the renowned process improvement strategy first started its journey from Motorola-USA. After its huge success over there, its application spread across the globe in manufacturing & service industries. The presented case study is the application of Six sigma in resistance welding process for defect prevention. The DMAIC methodology is used in the project, which is led by green belt. The paper discussed the different phases of Six sigma implementation with the application of relevant tools and techniques. The project team has identified different causes based on the collected data and classified based on their nature. The top contributing causes are identified and tested. DOE played a major role in validation of causes and identification of solutions. Finally, the solutions are implemented, monitored, and controlled to achieve the desired results. The project results which is an excellent zero-defect achievement is presented in the end.

Key words: Six sigma, Manufacturing, Resistance welding, Design of experiments, DMAIC, Process control.

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1. INTRODUCTION

Six sigma is a business change management and improvement model which is successful in implementation across the industries and gained world-wide recognition. Due to its global usage and higher returns, this methodology is evolving continuously with the academic and industry research in several fields of implementation. The major research is carried out in the manufacturing and service sectors which covers almost all categories of industries.

Six sigma is the process improvement methodology which is used in solving complex problems in manufacturing / service process areas [1]. Six sigma is successfully applied in all types of manufacturing processes from raw material ordering to finished goods delivery and with no exception of special processes like painting, welding, heat treatment, die casting etc. Similarly, it is employed in all service processes from order take up to order delivery.

Data collection and examining plays a pivotal role in successful project results. The major data handling processes include data cleaning, selection and transformation which in combination of these processes results in useful insights for problem understanding and resolutions [2]. It is crucial to understand how the data is used and the objective of data collection before commencement. The other important aspect is the type of data being collected i.e., quantitative / qualitative. The data collection plans are designed to suit the data type and purpose. In the recent years, data mining is being used in Six sigma projects for effective and quick data analysis. The key data mining techniques used are classification, clustering, association, prediction, time series analysis and sequential patterns [3].

Six sigma will be successful only if the top management of the organizations provides support throughout the deployment and committed for implementation [4]. Through Six sigma we can achieve both process improvement and personal development. Six sigma models will always have the training and problem-solving methodologies for successful implementation.

Six sigma is a methodology with set of tools for problem solving. Six sigma tools have been categorized in to three types:

- Basic tools: Process mapping, flow charts, check sheets, pareto charts, cause & effect analysis, histograms, run charts etc.
- Intermediate tools: Distributions, statistical inference, control charts etc.
- Advanced tools: Design of experiments, Regression & correlation analysis, process capability etc. [5].

In statistical terms, Six sigma is inferred as 3.4 dpmo. It is popularly used in fortune 500 companies across the globe. Over the period six sigma has been transformed from reducing the process variation to improvement of business processes [6]. There are two process methodologies for implementation of six sigma – DMAIC and DMADV. DMAIC methodology is used in resolution of existing process problems and DMADV is used in development of new processes / products / technologies.

With the wide use of Six sigma, learning and development has been played a prominent role in educating the employees and management for successful deployment. There are basically five levels of training programs established for different levels of organizational hierarchy based on their responsibilities [7].

- White belt: It is the basic level of training in Six sigma with the awareness and basic tools.
- Yellow belt: This level of training provides with Six sigma methodologies and tools to solve routine problems.
- Green belt: It is little advanced level with the set of tools and techniques to execute a business project under the guidance of black belts.
- Black belt: It is the advanced level of training with all the necessary tools, techniques and body of knowledge to execute the complex projects.
- Master black belt: It is the highest level of training with full body of knowledge on Six sigma which enables to execute multiple complex projects and mentoring the black belts.

Welding is a special process in the manufacturing industry, the optimization of the weld parameters is an area of interest in the engineering discipline which impacts the quality of the weld [8]. Six sigma helps in achieving the best weld quality through its statistical tools and techniques. There is 100 percent potential in reducing the welding defects, which results in the improvement of Six sigma level of more than 2 Six sigma [9].

According to Shashank Soni, the basic Six sigma tools & DOE techniques are best suitable for welding process in the DMAIC methodology [10]. The combination of tools used in various phases of DMAIC are depicted in the figure 1.

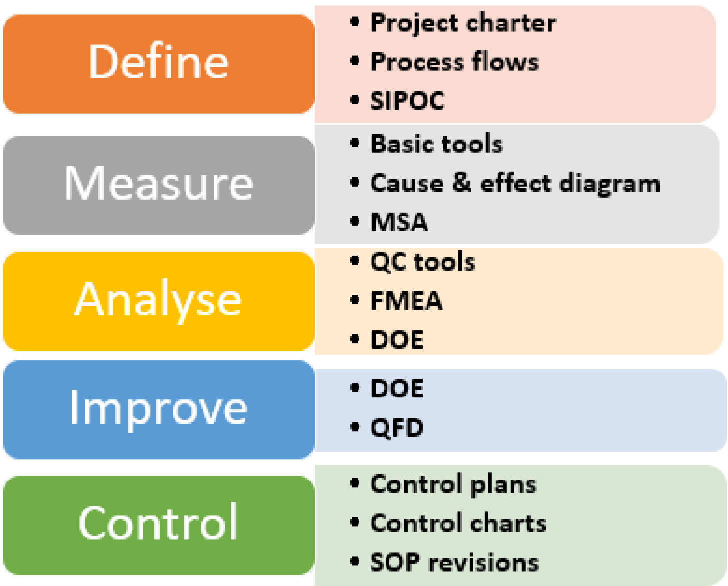


Figure 1 DMAIC Tools & Techniques

2. ANALYSIS

This paper presents the case study of the Six sigma green belt project on reduction of resistance welding defects in the manufacturing process. DMAIC methodology is used in this project.

Define phase: The project problem statement, project charter, present as-is process mapping & SIPOC is defined for clear understanding and planning of project.

Problem Statement:

Top cap Terminal Leakage at Bubble Leak Testing.

Project charter

- **Current status:** 8796 PPM (May-06).
- **Cost of Poor Quality:**
- 2,800/Compressor scrapped.
- Opportunity & Effort lost.
- **Objective:** Zero Defects (leakages) at Bubble Leak Test.

Champion: **M.Bhoopal Reddy**

Green Belt: **E.Santosh**

Team Members

M.Bhoopal Reddy

Padma Reddy

Surya Prakash

B.Srinivasa rao

Figure 2 Problem statement & Project charter

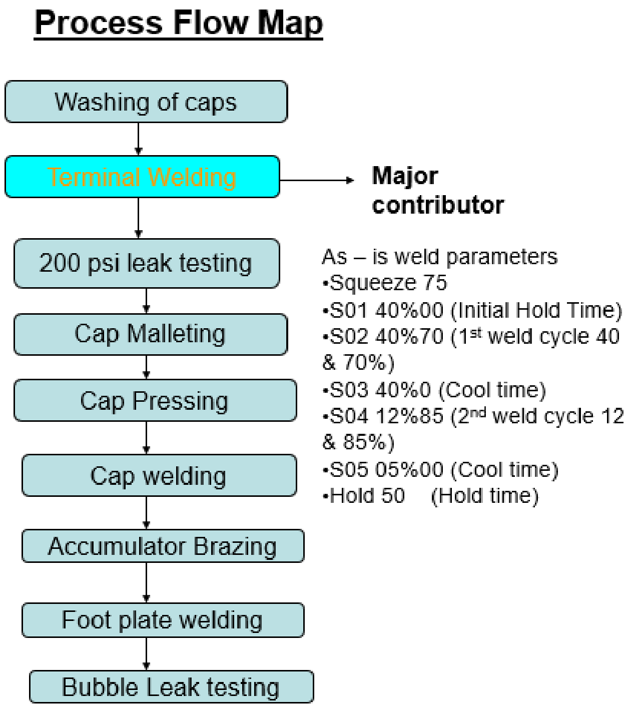


Figure 3 As is process map

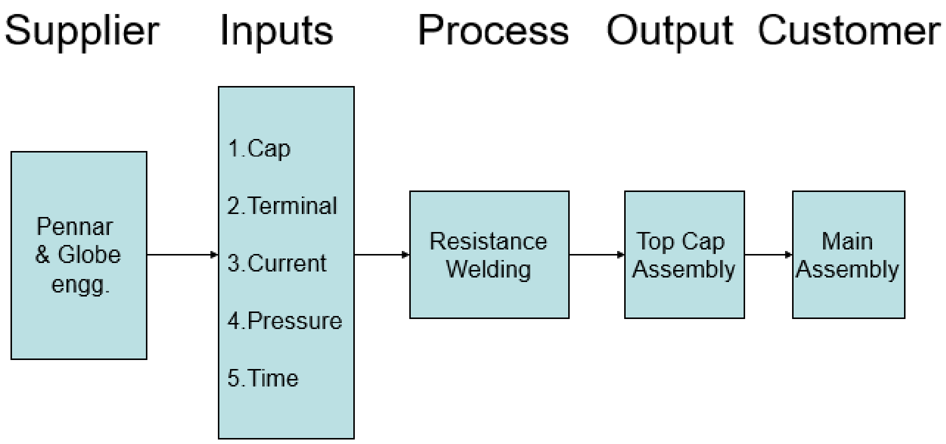


Figure 4 SIPOC diagram

Measure phase: It is very crucial phase of the project, as the data measurement plan and data collection are carried out for further investigations and improvement opportunities. The key parameter for weld quality is the weld strength, so the data collection is proposed for two pressure leak test points at 200 psi and 500 psi.

To know the exact leak area around the weld, the concentration identification diagram is prepared to make data collection tables accordingly.

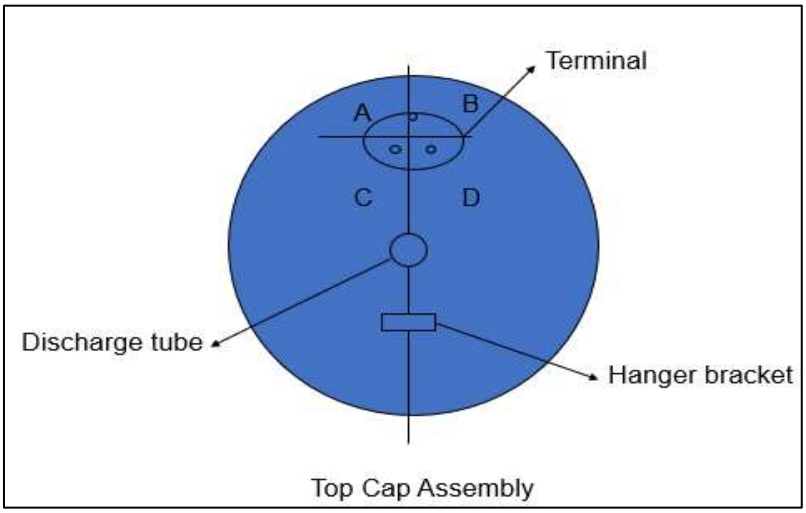


Figure 5 Concentration identification diagram

The test data is collected in the defect concentration table at 200 psi and 500 psi separately.

Table 1 Defect concentration data (@ 200 psi)

Day	Quadrant wise rejection				Total rejection
	A	B	C	D	
1	1				1
2		1			1
3				1	1
4				1	1
5			1	1	2
6				1	1
7			2	2	4

Table 2 Defect concentration data (@ 500 psi)

Day	Quadrant wise rejection				Total rejection
	A	B	C	D	
1		1		2	3
2		1	1	2	4
3				4	4
4				4	4
5			1	4	5
6			1	3	4
7			2	3	5

From the data, it is observed that the leakages are occurring more in C and D quadrants which are the point of investigation. It is also evident that the defect pattern is same at both 200 psi and 500 psi, so only 500 psi data is considered for further study. A brainstorming session is arranged with the experts and managers to identify the possible causes of leakages especially in the C and D quadrants. The following points are identified from the brainstorming session.

- Terminal hole size variation
- Point contact between cap hole & terminal
- Improper location of component
- Worn out of top and bottom electrodes
- Load variation from top electrode
- Burrs in the terminal hole
- Improper alignment between top and bottom electrode
- Height variation in between cap bottom face to top face

To understand the more possible causes from process point of view further data analysis is done and a fish bone diagram is prepared which is presented in Fig 6.

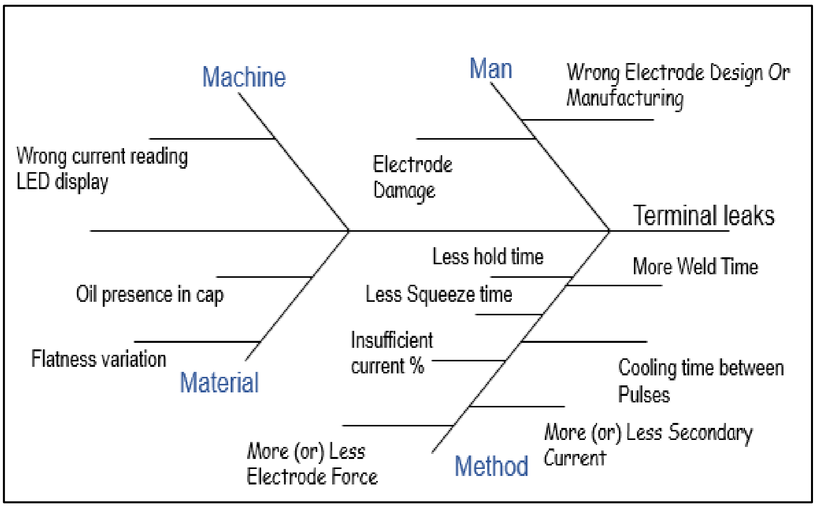


Figure 6 Fish bone diagram

From brainstorming and fish bone diagram the opportunities for error are consolidated and listed below:

- Wrong Electrode Design of land & relief angle.

- Electrode Damage.
- More (or) Less Electrode Force.
- More (or) Less Secondary Current.
- Weld Time.
- Insufficient Current % in Program.
- Cooling time in between weld phases.
- Hold Time.
- Squeeze Time.
- Erratic current reading in LED display.
- Oil presence in cap.
- Flatness variation around the terminal hole.
- Alignment of electrodes.
- Weld Current path.

From the opportunities for error and the defects data at 500 psi, DPMO is calculated to know the present Six sigma level.

Total parts tested (T): 513

Total parts rejected (R): 29

Total opportunities for error (E): 14

Defect per unit, DPU (R/T): 29/513 = 0.056530

DPMO = (DPU * 1000000) / E

= (0.056530 * 1000000) / 14

= 4037

At 4037 dpmo, the present Six sigma level is 4.15 which we need to improve it to 6 sigma level as per the stated objective.

Table 3 Function deployment matrix (FDM)

Key process output variables (KPOV)		**Weld leaks**	**Weld strength**	**Terminal damage**	**Metal flash**	**Priority (Product)**
Key process input variables (KPIV)		**Rating from 1 to 10**				
1	Electrode land & relief angle	8.5	7.5	2	2.5	319
2	Electrode damage	7.5	7.5	7.5	2.5	1055
3	Electrode force	9.5	9.5	3	5.5	1489
4	Secondary current	9	9	4	7.5	2430
5	Weld time	8.5	8.5	7.5	5.5	2980
6	Current % in program	8	8	7	5	2240
7	Cooling in between pulses	6.5	6.5	2.5	2	211
8	Hold time	8	8	1	2	128
9	Squeeze time	8.5	8	1	3	204
10	Oil presence in cap	6	6	2	2	144
11	Flatness variation	9	9	2	5	810
12	Alignment of electrodes	9	9	9	5	3645
13	Insulation of job	7	7	6.5	6	1911

To prioritize the actions, the function deployment matrix is used to rate the causes for prioritization with the key process input variables (KPIV) versus key process output variables (KPOV).

Analyze phase: The suspected causes are analyzed for their relationship and gaps with the problem and the solutions are devised in this phase.

The causes are stratified in to assignable and unassignable (refer table 4) to understand their nature and identification of key causes to address.

Table 4 Cause stratification

Assignable causes	Unassignable causes
Weld time	Electrode damage
Squeeze time	Alignment of Electrode
Hold time	Flatness around terminal hole
Cooling in between pulses	Insulation of job
Electrode force	Residue presence in cap
Electrode land & relief angle	
Current	

The key suspected sources of variation (SSV) are identified through FDM and stratification. To reduce the major rejections through attacking inherent process variations, the following five assignable causes are only selected for further analysis as per FDM priority rating which are referred in table 5.Thorough study of various fusite terminal specifications and process manuals, gaps are identified in the prioritized process parameters.

Table 5 Process gaps review

S#	Parameter	Present	Standard
1	Electrode land & relief angle	0 and 6 deg	0.218" and 45 deg
2	Electrode force	19200 N	15000 N
3	Weld time	40 cycle	20-30 cycle
4	Current	50 KA	60 KA
5	Cooling time in between pulses	40 cycle	20-30 cycle

Before going to next phase, it is important to benchmark the process to achieve the best possible solutions in the improve phase. The following process parameters are benchmarked with reference to the industry standards.

- Without weld leaks
- Weld strength of min 35 kg/sq.cm for 30 sec
- Without terminal damage
- Without metal flash
- With less heat generation

Improve phase: From the knowledge and information from previous phases, the best possible solutions are identified, actions implemented and tested for validation.

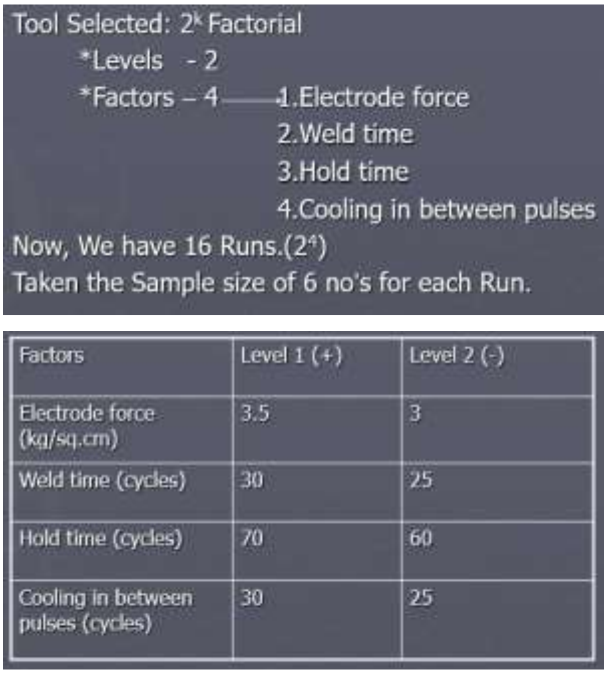
Out of five causes identified, one is related to fixture design and other are weld program parameters.

The existing top & bottom electrodes are replaced with increased land & relief angle. To accommodate this engineering change, the top cap drawing is revised with increased flatness area. A general experiment is carried out with the new electrodes to understand the changes on the process output parameters and the results are tabulated in table 6.

Table 6 Experiment results - 1

S#	Leaks	Strength	Metal flash	Terminal damage
1	Yes	100	No	No
2	Yes	100	No	No
3	No	150	No	No
4	No	140	No	No
5	No	120	No	No
6	No	155	No	No

From the above experiment, we had an improved result, but it is also clear that there are still the other program parameters are affecting the leaks and weld strength. To test the new electrodes with the revised weld program, Design of experiments (DOE) tool is selected for experimentation and the experiment design is presented in below fig 7.



Factors	Level 1 (+)	Level 2 (-)
Electrode force (kg/sq.cm)	3.5	3
Weld time (cycles)	30	25
Hold time (cycles)	70	60
Cooling in between pulses (cycles)	30	25

Figure 7 Experiment design

Based on the experiment design, the trail run design is prepared and tested as per table 7.

From the below experiment, the optimized process parameters which resulted in zero defects in the trail are:

- Electrode force – 3.0
- Weld time – 25.0
- Hold time – 95.0
- Cooling in between pulses – 25.0

Table 7 Trail run design

Trial	Electrode force	Weld time	Hold time	Cooling in between pulses
1	3.0	25.0	90.0	25.0
2	3.5	25.0	90.0	25.0
3	3.0	30.0	90.0	25.0
4	3.0	25.0	95.0	25.0
5	3.0	25.0	90.0	30.0
6	3.5	25.0	95.0	25.0
7	3.5	25.0	90.0	30.0
8	3.0	30.0	95.0	25.0
9	3.0	30.0	95.0	30.0
10	3.0	25.0	95.0	30.0
11	3.5	25.0	95.0	30.0
12	3.5	30.0	90.0	30.0
13	3.5	30.0	90.0	25.0
14	3.5	30.0	90.0	25.0
15	3.0	30.0	90.0	30.0
16	3.5	30.0	95.0	30.0

The "Should be" program was prepared using the above optimized parameter values as below.

Squeeze 75
S01 60%00 (Initial hold time)
S02 25%70 (1st weld cycle)
S03 25%00 (Cool time)
S04 18%85 (2nd weld cycle)
S05 05%00 (Cool time)
Hold 95 (Hold time)

Control phase: The identified solutions to be implemented and monitored for consistency in this phase. In some cases, fine tuning of the solutions are also accomplished based on the data monitoring and control.

Change action plan:

- Updating of Process sheet of new parameters.
- Revise the Electrode drawing.
- Update the SOP.
- Preparation of Control plan.
- Preparing & Monitoring the DPMO charts at 500 psi leak testing.

A control plan is devised with the process control parameters of inspection and testing with different frequencies and reaction plans. DPMO charts are prepared to monitor the defect level in conjunction with the control plans in case of any deviations. The initial data was taken for 15 days and the dpmo is improved from 4037 to 32 which is equivalent to 5.5 sigma level.

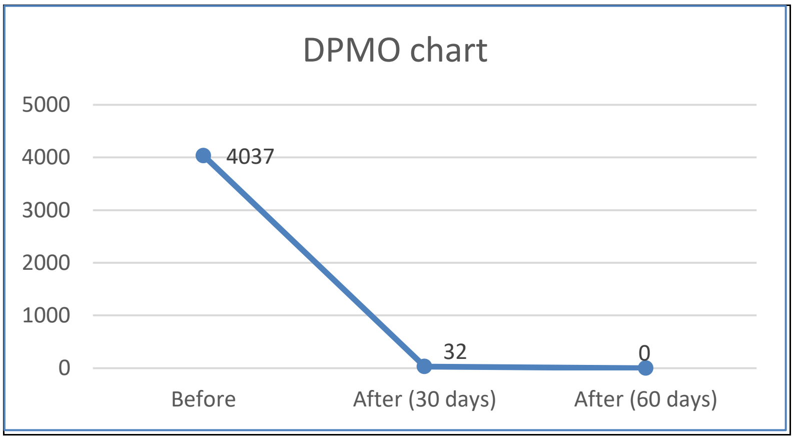


Figure 8 DPMO chart

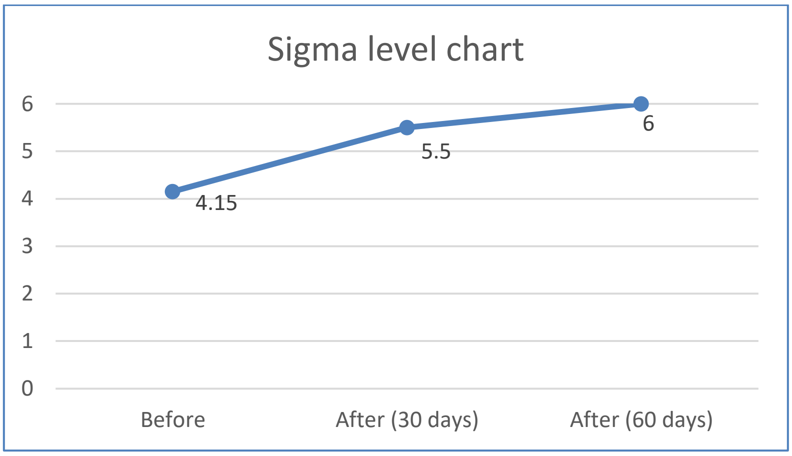


Figure 9 Sigma level chart

After monitoring the process for one month, the cause identified for 32 dpmo rejection is improper contact at the weld area. An immediate action plan of floating fixture is designed for uniform contact at weld area and implemented. The post action results are monitored for one month and the dpmo is reduced from 32 to zero which is a remarkable achievement of Six sigma level.

3. RESULTS & DISCUSSIONS

Six sigma had become most successful in attaining revolutionary results with the proliferation of corporate training and consultancy companies in the market. Even the successful corporate CEO's like Jack welch has propagated the Six sigma as a top business transformation model [7]. There is a huge untapped potential in the Indian business fraternity to take up this revolutionary business improvement model and achieve greater heights, which in turn helps to improve our Indian economy.

The DMAIC methodology of Six sigma is a proven model in manufacturing and service industries, which most of the times will result in positive outcomes. With the same inspiration, this project too yielded great improved results of Six sigma level. From project inception to completion, the entire team contributed to their best efforts in data collection, analysis, and implementation.

The management has shown keen interest in Six sigma deployment and supported the project team with all the required resources and freedom to execute decisions. This project has provided greater insights in to process problems and changed the perceptions in data handling and monitoring. It is also evident from the project course that the assignable causes are the only sources of variation and depicts that the unassignable causes will only disturbs the process if the process controls are not maintained adequately.

4. CONCLUSION

This paper presented the Six sigma methodologies and deployment patterns for attaining positive outcomes which improved from 4.15 sigma to 6 sigma level. A case study of green belt project is discussed with phase wise process and outcomes as per DMAIC methodology. This project had proved that Six sigma can even be applied to any special manufacturing processes and achieve remarkable results.

From the discussions, it is impeccable to accept that Six sigma can be great model for business and process reengineering / transformations.

5. FUTURE SCOPE

There is ample opportunity to deploy Six sigma in the other welding processes like soldering, under water welding, gas welding etc. It can also be extended to small scale industries with proper trainings and support from the local governments. There is also potential to implement Six sigma in unexplored areas like space exploration, Climate control, and community development sectors in the future research.

CONFLICT OF INTEREST

The authors confirm that there is no conflict of interest to declare for this publication.

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