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## REDUCTION IN CYCLE TIME VARIATION OF CONVEYOR DRIVEN ENGINE ASSEMBLY LINE BY IMPLEMENTING SIX-SIGMA

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### ABSTRACT:

Since the inception of the six-sigma implementation has been done for the defects which are tangible which affects the functionality of a product significantly viz. deviation from mean diameter of a shaft, oil seal leakages, frequently defects occurring in an assembly etc. A little research is done on intangible defects. Here intangible defect means a defect does not cause any harm to functionality of the product. For instance, while assembling a product an operator does not follow standard time which is being assigned him or her to perform the task. An assembly time required for a certain task-the time here is an intangible parameter (no materialistic existence and no effect on functionality of the product). One can measure the time but cannot realize its physical existence and this research tries to consider details of reduction of cycle time variation of conveyor driven manual engine assembly line. Here, First, Conveyor driven means; an engine is mounted on the pedestal and is moved forward and backwards by means of a conveyor. And second, manual assembly line means no robots are involved all the processes are performed by human operators. The crossing of given standard time is or completing given task in far much less time considered as a defect in this research. To reduce cycle time variation and over or under cycle time here the six-sigma methodology is implemented.

**KEYWORDS:** Conveyor Driven Assembly line, Andon Call, Cycle Time Variation, Six Sigma, Process capability, Intangible Defect.

### 1. INTRODUCTION

Six Sigma is organized and methodical for strategic process enhancement, new product and service development that relies on statistical methods as well as the scientific method to make dramatic falls in customer-defined defect rates. Six-Sigma at many establishments simply means a measure of quality that attempts for near excellence. Six-Sigma is a disciplined, data-driven methodology for eliminating flaws (achieving six standard deviations between the mean and the nearest specification limit) in any process – from manufacturing to financial transactional and from product to service; statistical thinking is a method used as part of Six-Sigma methodology. This study deviates from the conventional approach of Six-Sigma methodology to any industrial problem. Defects are considered in terms of time as a controlling parameter- an intangible parameter.

The research about which this paper deals with was from an automobile engine manufacturing facility. Conveyor driven engine assembly line is used in this facility which has a defined speed at which it moves along the defined path. The assembly line consists of five teams and 29 stations in total [13]. But, to provide sufficient insights regarding this Six Sigma project out of five teams only one team is examined thoroughly and among the stations of the selected team only single station is analysed and presented completely in this paper. Rest stations of the selected team have got final results of the project.

Here, the conveyor driven assembly line is studied for its cycle time and cycle time is considered as the measuring parameter for this study. In this study, Standard Cycle Time (SCT) of a station on a moving assembly line is the basis of reference. Traditionally, the defect is said to be generated when a certain parameter goes out of specification. Here cycle time being the

parameter if it exceeds the given limits i.e. Upper Statistical Limit (USL) which is SCT and Lower Statistical Limit (LSL) which is 95% SCT then a defect is said to be generated. It means that operator of a station must finish his or her assigned task within USL and LSL. Although time is an intangible parameter; we only can sense it and measure it but cannot see its physical existence. Therefore 30 cycles are observed for cycle time and recorded with the help of stopwatch. The study has done for two shifts i.e. shift A i.e. morning shift from 6.30 AM to 3.15 PM and shift B i.e. evening shift from 3.15 PM to 11.30 PM. [13]

Now for understanding let us consider a station, an operator is assigned to some activities to perform at that station. The operator has given Standard Operation Sheet (SOS) which consist of breaking of the task in sub-activities which cannot be broken further. A standard time is mentioned in the sheet for an activity. Its operator's duty to perform these activities within USL and LSL to maintain the quality of time management.

Since it is mentioned that a single station of the assembly line is taken as a case for this paper. Hence, the total production of the engine for a given station is the total production of the assembly line since each engine must pass through the given station. Now, each station has different cycle time to as station perform them respective processes and so does cycle time variation also different. There is a fair chance for each station's operator to pull Andon chord for a given engine till its assembly processes get done on that station. By refereeing to Andon call as theeffect which is generated at a given station may not affect the functioning of the engine, since, thereis only concern about the cycle time variation and its causes. Details of Andon and respective defect are explained in subsequent paragraphs.

### 2. LITERATURE REVIEW

Ashok Patole et al (2012) have sought attention on limitations of Six Sigma implementation and failure of the Six Sigma projects

undertaken by various organisations. Their paper outlined eleven ways of Six Sigma failure and these are as follows- i) Lack of commitment from the top of the leadership pyramid. leadership must walk the talk. Mere talking in meetings and email greetings will certainly lead to failure of Six Sigma project. ii) Lack of Devotion from Middle of the organisational pyramid. which can be considered as the backbone of the Six Sigma Project implementation. iii) Part-time black belts. iv) The linkage between the project's objectives and organisational goals. Emotions and sentiments of the top management have not been conveyed to bottom down in failed Six Sigma projects. v) No monitoring or review mechanism vi) Absence of reward and punitive system. vii) Effective and robust infrastructure to teams working on projects. viii) Duplicating project from elsewhere without understanding the own needs and limitations. ix) Outweighing quantity over quality. x) Over usage of statistical tools where it really does not require. Emphasis should be given to flexibility of use of tools. xi) Impatient for results. Six Sigma is a philosophy and one need to adopt it; for that enough time should be given to the project team and their supporters. An analogy of the stress-strain diagram is provided to project implementation. It goes as Stretching Phase, Yielding Phase, Failing Phase.

Ashok Patole et al (2011) presented a fusion of Six Sigma and Lean Management as Lean Six Sigma. This paper gives definitions, significance and conceptual explanation of the Six Sigma as a statistical tool. In further reading through the paper, it reveals that the author has explained the historical development of lean management philosophy. It shows various waste and source of waste generation. Here, explicitly mentioned that the most Six Sigma project requires the application of Lean concepts e.g.- Cycle time reduction. An attempt is done to integrate DMAIC (Define, Measure, Analyse, Improve and Control) to Lean Management- in Define phase of DMAIC; seven type of waste is incorporated. Accordingly, various features of Lean have incorporated in the Six Sigma philosophy.

Harshwardhan and Naresh (2018) have successfully implemented Lean Management to a case study to reduce wastes and optimise a number of operators in the kitting area of Global Propulsion System of General Motors India Pvt Ltd Pune plant. The template was made to identify the seven types of wastes. To gather data on these wastes a questionnaire was also made. This questionnaire was used to identify and give feedback from various personnel who were associated with the kitting area. By implementing the Lean philosophy authors were able to reduce operators from eight to seven and a significant amount of expenditure reduced.

Adrian Pugna et al (2016) have used Six-Sigma for improvement of the quality of horn assembly. They carried out 10000 observations out of which 801 were defective and 319 were only due to the incorrect height of rivet was contributing maximum numbers for a defect in the horn assembly. Authors have applied the DMAIC approach of Six-Sigma. After analysing the rivet installation process, they found incorrect force applied by the operator and modified the hand tool also they incorporated poka-yoke device. A supplier is selected from the AHP analysis.

James E. Brady et al (2006) did a research study on Six-Sigma. This study is an attempt to answer the fundamental questions: (i) What is Six-Sigma? (ii) What are its impacts on operational performance? and (iii) What roles can academics usefully play in relation to Six-Sigma? Low Shye Nee used the lean methodology to hit the problem. the proposed solution based on the concept of Lean production increase profitability based on idling time reduction (81.64%) and operator saving (40%) in operation.

Dr R.L. Shrivastava et al (2008) used Six-Sigma to tackle the problems which arose from the customer end. Problems are like water and oil leakages from engines leading to customer dissatisfaction. Total PPM for Engine Quality was 7243 PPM. Cost of poor quality was approximated at \$ 30,000 per annum. Problems at Vehicle Mainline due to Engine Quality issue to be reduced from 7243 PPM to 700 PPM.

Mayur Patil (2015) used a six-sigma statistical approach to improve quality of engines on an engine assembly line. He used SIPOC (supplier, inputs, process, output & customer), DMAIC, Pareto analysis, WHY-WHY, and Ishikawa diagram analysis to study and analyse the issues regarding frequently occurring defects in the engine at customer's end. The results were obtained by the author are, an increase of process sigma level from 3.8 to 4.5 and defects reduced from 9684 Defects Per Million Opportunity (DPMO) to 1500 DPMO.

M. White et al (2009) did a study on Business Accounts and considered a reduction of the cycle time for possessing credit account. The paper talks about 'Financial Six Sigma Project'. Here, DMAIC is the approach to resolve the issue. The authors say that the industrial application of the six-sigma is extensive while the services applications are difficult to observe. Authors found out a way to improve quality of service in banking institutes. The problem was defined as the time required to open a loan account was 45 days which is quite long hence, they want to reduce it from 45 to 30 days. To tackle this issue, activities required to open an account were categorized as value added, business value added, and non-value added. On the basis of data collection and analysis, they prepared an action plan and implemented it and seen the significant net saving of \$345,000.00 in the 1st full year of implementation.

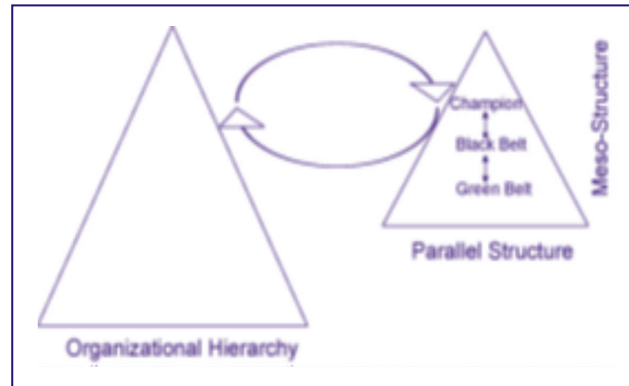
Adan Valles et al (2009) discussed the six-sigma project conducted at a semiconductor company dedicated to the manufacturing of circuit cartridges for inkjet printers. It found that electrical failures accounted for about 50 % of all defects. DMAIC methodology is used to execute the six-sigma method. ANOVA is used to show if there any variation among the batches. Sigma level improved from 3.35 to 3.72 and elimination 1.88% of defects.

Amit Yadav and Sukhvani (2016) improved quality of clutch of an automobile by implementing Six Sigma. The paper has a literature review which is certainly related to their project. All the literature cited in the paper goes for tangible defects which can directly impact the functionality of the product.

Roger G. Schroeder et al (2007) did significant work on defining Six Sigma and its underlying theories. Paper argues that

academic research work is little as compared to industrial practice. Approach to do research the Grounded Theory was used. Authors have asked three fundamental question to give justice to the title of the paper-i) What are the base definition of Six Sigma and possible variants? ii) What is the theoretical basis underlying Six Sigma? iii) What is new about Six Sigma relative

to the existing literature? Two companies are selected one is in the manufacturing sector and another is in the service sector; both have implemented Six Sigma Project successfully. Elements of Six Sigma Projects; Parallel Structure- which operate parallel to existing operations of an organisation without hampering organisation's regular activities.



**Fig. 1. Six Sigma Project works parallel to the regular activities of an organisation.**

Six Sigma acts as a switching mechanism in an organisation and it is supported by a parallel structure. So far from the literature review, it is found that a little work has done for assembly operations and few have considered cycle time as controlling or judging parameter. Cycle time, since is an intangible aspect of the assembly process, this project tries to shed some light on this untouched area of the manufacturing processes and implementation of six-sigma to reduce cycle time variations and to increase productivity if the engine manufacturing facility. (Here, the 'intangible' word is used to connote time has no physical or materialistic existence for which one can touch and say a 'Defect' is generated by violating given standard time to perform a task. Oxford dictionary defines the word 'intangible' as an 'adjective'; a thing that exists but that is difficult to describe, understand or measure.)

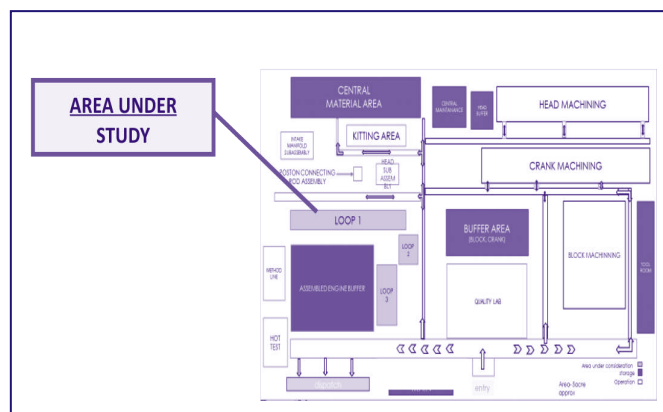
**3. PROBLEM AT AUTOMOBILE ENGINE MANUFACTURING FACILITY-DEFINITION OF A PROBLEM**

Assembly line is one of the most widely used production systems. The productivity of a manufacturing system can be

defined as the amount of work that can be accomplished per unit time using the available resources. Agrawal (2010) [4] defines assembly line productivity as how well a production system uses its resources to achieve production goals at optimal costs. The conventional productivity metrics, namely throughput and utilization rate give a substantial measure of the performance of an assembly line. the engine build process is carried out on moving assembly line. Assembly line is divided into three loops i.e. Loop 1, loop 2, loop 3. The main problem on moving assembly line is the uptime is lower than 90% which is the benchmark of the plant.

For this six-sigma project the objectives are as follows:

- Calculate  $C_p$  &  $C_{pk}$  for each station on the line and then find out the cause of variation and try to minimize the process variation from the target station.
- Define current process sigma level and improve to achievable level.
- Current over speed is 10%, planned to reduce up to 2.7%.



**Fig. 2. The automobile engine manufacturing plant layout.**

The above figure 2 shows the automobile engine manufacturing plant layout. Here the project is conducted at loop 1 as shown in the figure. Loop 1 is the main assembly line which is conveyor assisted and moves at a constant speed. The stations are marked on the line with the help of colour strips as shown in following figure 3.

**DMAIC Methodology Implementation**

**3.1. Define Phase**

In the define phase, various terms and concepts are defined and as well as explained in detail.

**3.1.3 Operations:**

Station	Operations
A4.01.100(TM1 & TM2)	Piston stuffing in the cylinder block
A4- 01- 110	Vision system to check orientation and placement of pistons
A4- 01- 130	Torque to turn the Crankshaft
A4- 01-140	Cylinder head dowel and gasket insertion and installation
A4- 01- 180/190	Camshaft placement

(A4- 01- 180/190- depending upon the engine variant station 180 or 190 is used)

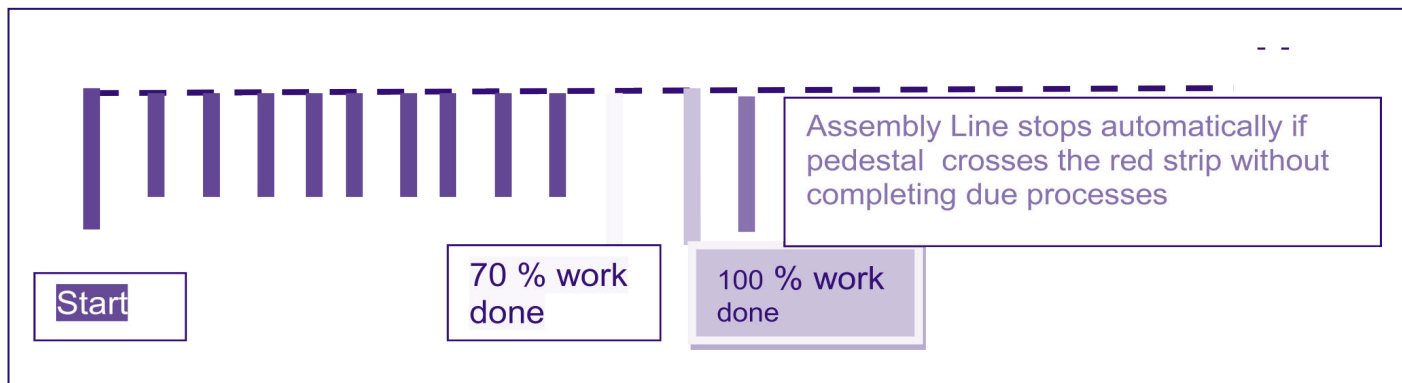
**3.1.4 Defect:** Defects in Terms of Cycle Time for a Conveyor Assembly Process. A defect will be said generated if an operator repeats the process and while doing so he pulls the Andon chord. Even if the problem is not solved then the assembly line will automatically stop, hence, cycle time will increase for a station

**3.1.5 Station:** Below fig. 3 shows a typical station on the assembly line. Colour strips are marked next to conveyor to define a station. Station start on a green strip and ends at a red

**3.1.1 Team:** A 'Team' is a collection of operators who perform assigned tasks. Team members vary in number since station allocation to a team varies. Here, among five teams, Team 2 is under study.

**3.1.2 Team Member and its Leader:** Team two has six members in total (Station A4-01-100 has two operators to perform given task). These six members were assigned to each station of the team 2. Every station has one member assigned except station A4-01-100; it has two members to perform piston stuffing in a cylinder block.

strip. By the time the engine carrying pedestal comes to yellow strip 70 % of the activities should be completed by the operator. There is buffer spacing is provided to complete remaining activities. If an operator fails to perform all activities by the time he comes to the red strip, then the assembly line stops automatically. The spacing between the strips is decided on the basis of the time required to perform each activity. If an activity takes more time, then large spacing is between the strips and vice-a-versa



**Fig. 3. Colour strips marked for a station from start to finish.**

**3.1.6 Over cycle:** An operator starts his work when both the orange strips coincide (ideal situation) and stops at red strip since he or she is not allowed to cross the red strip; the consequence of this might be disturbing the operator next to him or her. After reaching the red strip the operator must return to the orange strip to start the next cycle. If for the operator, it is not possible to finish his or her activities by the given cycle time, then one provision is given to stop the line and i.e. Andon chord.

**3.1.7 Andon board and call:** Andon is a manufacturing

feature which is used to bring management, maintenance personnel and other workers in the notice for quality or process problem. Figure 4 below shows a typical Andon board. A situation comes when the operator cannot finish his or her assigned assembly activities then the operator is told to pull the Andon chord which provided near to the station to stop the conveyor assembly line, thus, he or she can resolve the issue with help of senior personnel assistance. This feature of shopfloor is used to calculate Defects Per Million Opportunity (DPMO).

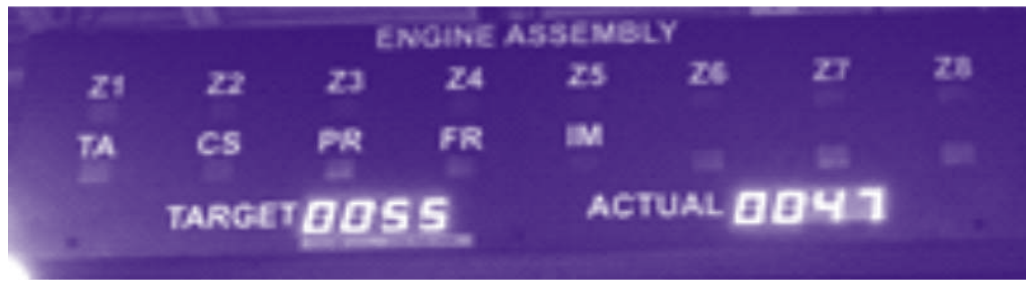


Fig. 4. A typical Andon Display Board

**3.1.8 Specific limits i.e. Upper and lower limit:** It was observed that Andon calls are high in team 1 & team 2 compared to other three teams owing to this production rate were decreasing and uptime was less due to variation in cycle times.

**3.1.9 Assembly line:** An assembly line is consisting of a fixed number of assembly station at which various parts, components

and subassemblies are brought together to make a final product. Following figure 5 gives detailed classification on types of assembly facilities are given. The station which high cycle time among all the stations would define the final output of the line; hence the large variation in the cycle time of a single station can hamper the output.

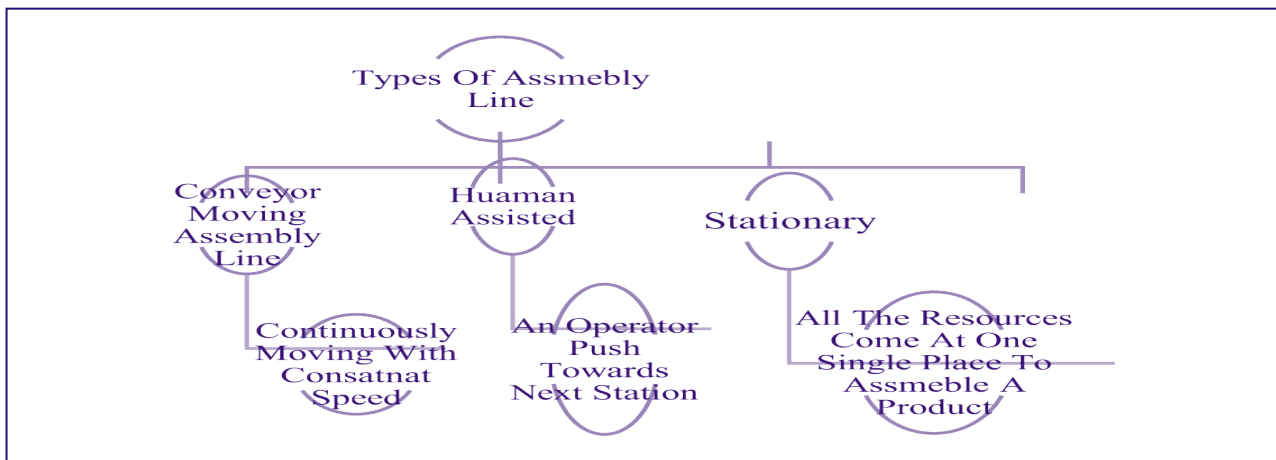


Fig. 5. Types of the assembly line

**3.2. Problem identified as follows**

Following table 1 shows the actual production data versus plant capacity and production loss in percent. Capacity is taken as working days in a month to capacity per day.

**Table 1. Production loss during Dec 16- Feb 17 in percentage.**

Month	Actual	Capacity	Production Loss %
DEC	10065	10224	2
JAN	8925	9798	9
FEB	8919	9798	9

It was observed that Andon calls are high in team 2 (Fig 2.) compared to the other four teams owing to this production rate was decreasing and uptime was less due to variation in cycle times. To have quantified data of variation in cycle time; 30 cycles for each station for both shifts are recorded in measure phase. And to provide evidence to variations Andon calls are recorded for the same period when cycle time is recorded. The production loss shown in table 1 is not merely Andon calls this may include other losses also.

**3.3. Measure Phase**

Actual takt time is 129s; hence conveyor moves an engine

mounted pedestal from one station to the next station within 129s. Strips are marked on the floor so that the operator should know his working area. For this study cycle time for all the 29 stations were recorded. On that basis, all the statistical calculation such as average cycle time, process capability, process capability index is calculated with the help of these recorded cycle time. Cycle time for all stations was recorded, causes of variations were written down.

**3.3.1. Andon call recording:** Andon calls reasons are recorded by the team leader of the team and an automatic computer system keeps the quantified data of the Andon calls such as the time for which the assembly line stopped, the date and the shift.



**Fig.6. The Andon call total over the period from December 2016 to February 2017**

Here, data is collected for two shifts and all the stations of the team 2 but, only one station is analysed and presented i.e. A4-01-110, this very same philosophy and methodology have been implemented to other stations. The Station which is undertaken for the case study i.e. A4-01-110 has a yield of 97.78%. (Table 7.)

**Note:** Here, Andon calls are referred as cause for the defect generation by the assembly line (causes may be anything such as defective part, subassembly, operator would be under skill etc.) owing to which the operator had to repeat the cycle to just ensure whatever defect was generated was resolved and now the partly

or completely engine is defect free (all the required activities/processes are done while assembling the engine). While doing so the line could have stopped for many times this certainly led to variation in cycle time. By refereeing to Andon as defect may not affect the functioning of the engine, since, we are only concern about the cycle time variation and its causes. Here, an attempt is made that only a single station is considered for presenting the research work, as already mentioned in the introductory part. Station A4-01-110 has the highest Andon Call count among other stations. Following table 2 gives total Andon Call count from December 2016-February 2017.

**Table 2. Andon call count for the station A4-01-110**

Station	Team 2 issues	Count from Dec 2016 - Feb 2017
A4-01-110	Vision system	466

**3.3.2. Cycle time recording:** Below Table 3 shows average cycle time readings for the station A4-01-110. The cycle time has been recorded with the help of electronic stopwatch (Samsung Tab A, 2015 Model) and the video recording by a video recorder (Sony

Camcorder). 30 cycles were observed for each shift for a given station. Hence there are two samples of 30 readings. Shift wise operator was changed. Shift A starts at 06.30 am and ends at 03.15 pm. Shift B starts at 03.15 pm to 11.30 pm.

**Table 3. The average, Maximum, Minimum and Standard cycle time of station A4-01-110**

Station No	Average cycle time (seconds)	Max cycle time is taken by an operator (seconds)	Min cycle time is taken by an operator (seconds)	SCT (seconds)	ATT (seconds)
A4-01-110	105.0	133.0	85.0	115	129.0

**3.4. Analysis Phase**

All the cycle time readings were put into Microsoft Excel sheet for the calculations of  $C_p$  and  $C_{pk}$ . Calculations are shown here for

team 1, in similar way calculations were done for others team also.

3.4.1. Normality Test for station A4-01-110.

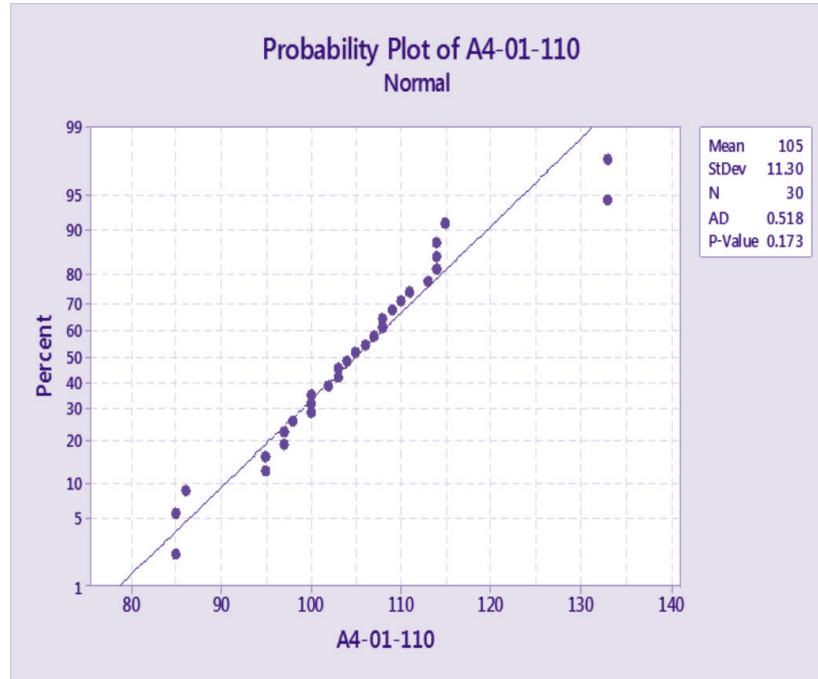


Fig. 7. Normality test for the station A4-01-110

Table 4. Normality Test Based on the P value

Station	Mean	Standard Deviation	Total count	Anderson-Darling	P value
A4-01-100 (TM1)	87.5	6.135	30	0.958	0.013
A4-01-100 (TM2)	104.1	5.387	30	0.259	0.691
A4-01-110	105	11.30	30	0.518	0.173
A4-01-130	114.3	12.80	30	0.359	0.429
A4-01-150	115.8	14.16	30	0.317	0.522
A4-01-180/190	123.3	8.247	30	1.682	<0.005

Some station has P value less than 0.05 which can be justified by the fact that psychology of the operator at the time of operation, the health of the operator and any other personal circumstances while performing the tasks. Apart from these stations, other station's reading falls under the normal distribution. (If the p-value is greater than 0.05 then the data is normally distributed.)

**3.4.2. Process capability calculation:** Let us consider a calculation for station no A4-04-110 as shown following.

**USL- Upper specific limit**= SCT= 115 sec

**LSL- Lower specific limit**= 0.95×SCT= 0.95×116= 109.25sec

**Mean (μ)**= 105sec

**Standard deviation (σ)** = 11.3 sec

The below figure 8&9 gives the process capability values for team 2 and for the shift 1. Since the station, A4-01-100 has two operators i.e. team member 1(TM1) & team member 2(TM2) it is indicated in the above figure 7. The following formula used to calculate process capability.

$$Cp = \frac{USL - LSL}{6\sigma} = \frac{SCT - 0.95 \times SCT}{6 \times \sigma} \tag{1}$$

$$Cpu = \frac{USL - \mu}{3\sigma} \tag{2}$$

$$Cpl = \frac{\mu - LSL}{3\sigma} \tag{3}$$

$$Cpk = \min(Cpl, Cpu) \tag{4}$$

Where, TM1 is team member 1 and TM2 is team member 2 of Team 2.

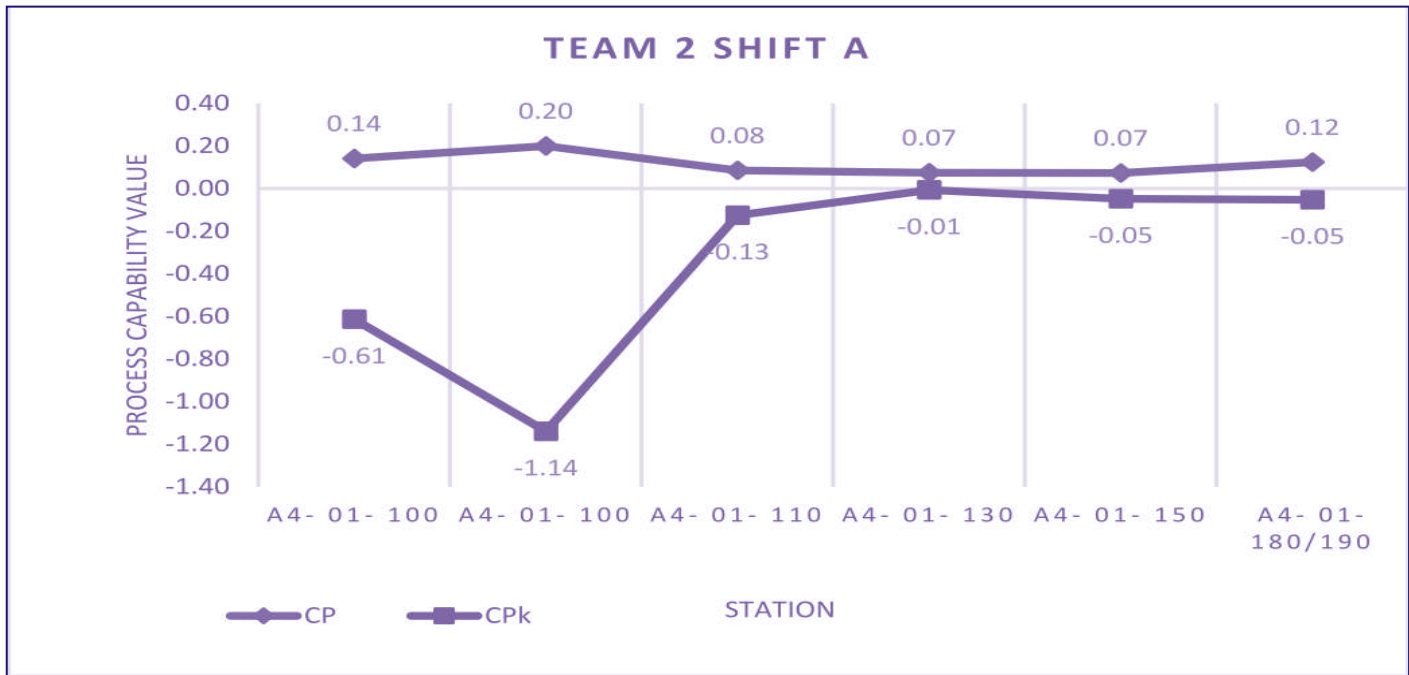


Fig.8. Team 2 shift A process capability Analysis

Table 5.  $C_p$  &  $C_{pk}$  values for team 2 stations of shift A

Station No.	A4-01-100	A4-01-100	A4-01-110	A4-01-130	A4-01-150	A4-01-180/190
$C_p$	0.14	0.2	0.05	0.07	0.07	0.12
$C_{pk}$	-0.61	-1.14	-0.97	-0.01	-0.05	-0.05

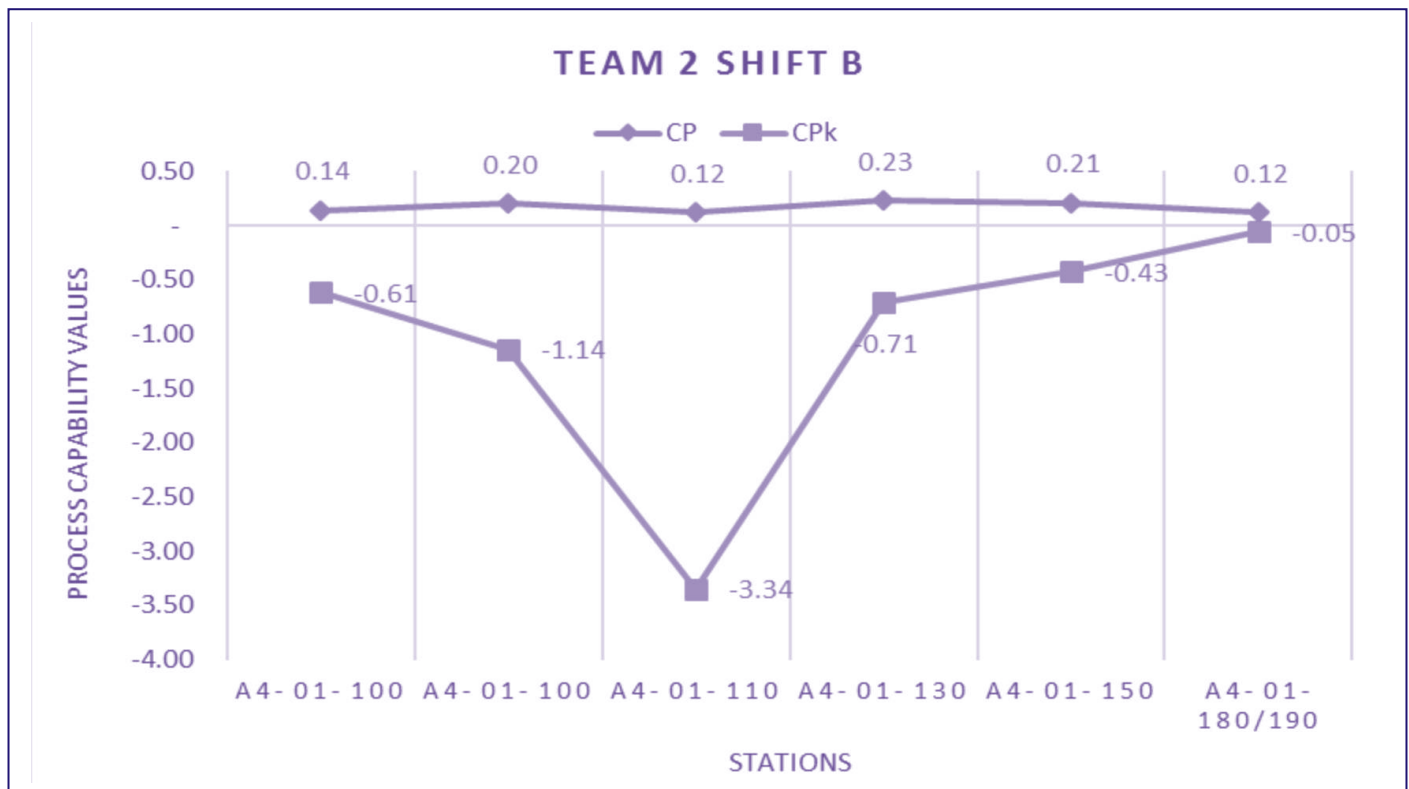


Fig.9. Team 2 shift B process capability Analysis

**Table 6: Cp & Cpk values for team 2 station of shift B**

Station No	A4-01-100	A4-01-100	A4-01-110	A4-01-130	A4-01-150	A4-01-180/190
Cp	0.14	0.20	0.12	0.23	0.21	0.12
Cpk	-0.61	-1.14	-3.34	-0.71	-0.43	-0.05

**3.4.3. Implications of process capabilities**

i. Case 1: CP > 1.33

A fairly capable process. This process should produce less than 64 non-conforming PPM. This process will produce conforming products as long as it remains in statistical control. The cycle time variation will fall below 64 cycles per one million cycles.

ii. Case 2: 1 < CP < 1.33

A barely capable process. This process will produce greater than 64 PPM but less than 2700 non-conforming PPM. This process has a spread just about equal to specification width. It should be noted that if the process means moves to the left or the right, a significant portion of the product will start falling outside one of the specification limits. This process must be closely monitored. This process is contained within three to four standard deviations of the process specifications.

iii. Case 3: CP < 1

A not capable process. This process will produce more than 2700 non-conforming PPM. It is impossible for the current

process to meet specifications even when it is in statistical control. If the specifications are realistic, an effort must be immediately made to improve the process (i.e. reduce variation) to the point where it can produce consistently within specifications.

iv. Case 4: CP < 1

A not capable process. This process will also produce more than 2700 non-conforming PPM. The variability and specification width is assumed to be the same as in case 3, but the process average is off-centre. In such cases, the adjustment is required to move the process mean back to target. If no action is taken, a substantial portion of the output will fall outside the specification limit even though the process might be in statistical control.

**3.4.4. Present process sigma level of team 2**

For calculation of DPMO, a number of defects are considered as the number of Andon Calls generated. Following the table, 7-gives existing Sigma level of process for Team 2 from the month December 2016 to February 2017. Here, Sigma level is presented for the whole Team 2.

**Table 7. Production data and process sigma level, Defects, Yield for month December 2016**

OPERATION	Total Andon Call for December	TOTAL ENGINE PRODUCED	CURRENT SIGMA LEVEL	DPMO	DEFECTS %	YIELD %
A4-01-100	27	10065	4.3	2683	0.27	99.73
A4-01-110	241	10065	3.5	23944	2.39	97.61
A4-01-130	85	10065	3.9	8445	0.84	99.16
A4-01-140	28	10065	4.3	2782	0.28	99.72
A4-01-150	100	10065	3.8	9935	0.99	99.01
A4-01-190	52	10065	4.1	5166	0.52	99.48

**Table 8. Production data and process sigma level, Defects, Yield for month January 2017**

OPERATION	Total Andon Call for December	TOTAL ENGINE PRODUCED	CURRENT SIGMA LEVEL	DPMO	DEFECTS %	YIELD %
A4-01-100	37	8925	4.14	4146	0.41	99.59
A4-01-110	207	8925	3.49	23193	2.32	97.68
A4-01-130	71	8925	3.91	7955	0.8	99.2
A4-01-140	72	8925	3.91	8067	0.81	99.19
A4-01-150	106	8925	3.76	11877	1.19	98.81
A4-01-190	87	8925	3.84	9748	0.97	99.03

**Table 9: Production data and process sigma level, Defects, Yield for month February 2017**

OPERATION	Total Andon Call for February	TOTAL ENGINE PRODUCED	CURRENT SIGMA LEVEL	DPMO	DEFECTS %	YIELD %
A4-01-100	24	8919	4.28	2689	0.27	99.73
A4-01-110	173	8919	3.57	19384	1.94	98.06
A4-01-130	58	8919	3.98	6499	0.65	99.34
A4-01-140	29	8919	4.22	3249	0.32	99.68
A4-01-150	58	8919	3.98	6499	0.65	99.35
A4-01-190	177	8919	3.56	19382	1.98	98.02

The present process sigma level for each month and station is shown in table number 7, 8 and 9. From these data average sigma level is drawn, and which is shown in following figure 8. The actual and plant capacity is shown in above table no 1. Current process sigma level of each station of team 2 is shown in following figure 8. Here, it can be seen that the station which has the highest Andon calls has least sigma level. The objective of

the project to increase the process sigma level and strive for six sigma implementations. From figure 8 below it can be learnt that station A4-01-110 has least process sigma level amongst the team 2 and that station is to be taken for the action. Here, the reader can have justification for selection of station A4-01-110, since it has highest Andon Calls as well as least process capability index.

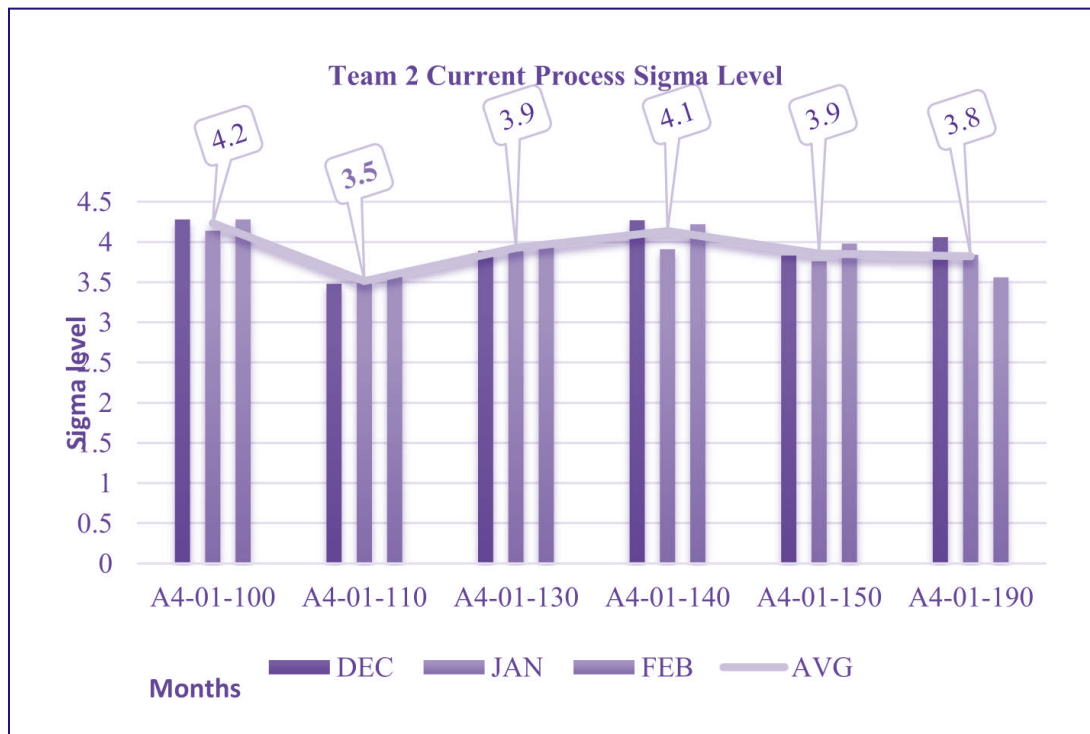


Fig. 10. Process sigma level for the team 2

3.5. Causes of variation

Actual problems/ Cause of variations which were observed are as follows (Top three need to tackle first).

Table 10: Cause variations in cycle times

Operation	Team 2 Issues	Count from Dec 2016 - Feb 2017	Causes
A4-04-110	Vision system	466	<ol style="list-style-type: none"> <li>1. Faint colour, images are not clear</li> <li>2. The camera doesn't sense in one go</li> <li>3. Tool eccentricity, bush wear</li> </ol>

3.6. Implementation Phase

In the six-sigma project after analysing phase, the next phase is to implement the solutions to check the results and their effectiveness. All the countermeasures and modifications are listed in following table 3.16 and 3.17. For the station A4-01-110 issue was vision system the main causes were faint colour on the

piston. The piston is coloured with colour code red, yellow, green and blue the reference colour code picture or image is given to the system which is very high quality i.e. of 1080 pixel and the camera is fitted is 128 pixels hence the matching of the reference picture and the actual one is not possible. Therefore, it very often required to restart the vision system and get corrected the issue.

Table 11. Cause of variations and their countermeasures

Station	Team 2 Issues	Reasons	Counter Measures
A4-01-110	Vision system	1. Faint colour, images are not clear	1. New images with higher quality are stored in the system
		2. The camera doesn't sense in one go	2. Installation of higher quality camera
		3. Tool eccentricity, bush wear	3. Design of new bush with stainless steel material

3.7. Control Phase

The next phase after the implementation phase is the control phase and is also the last step in six-sigma project.

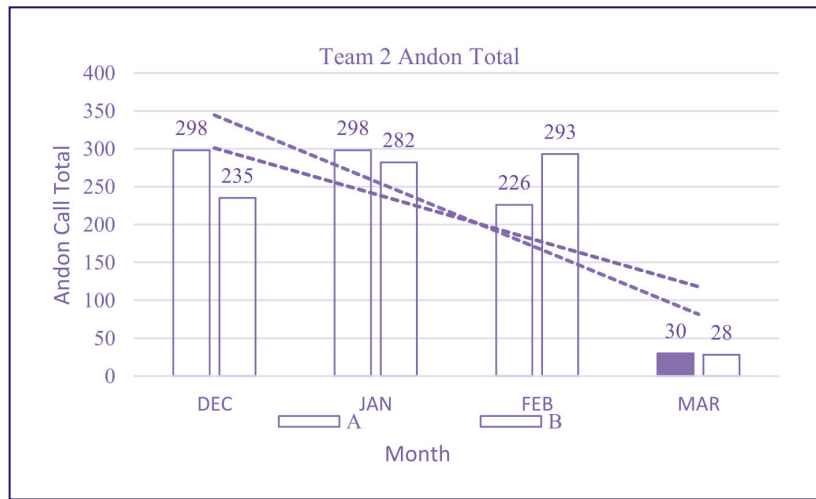


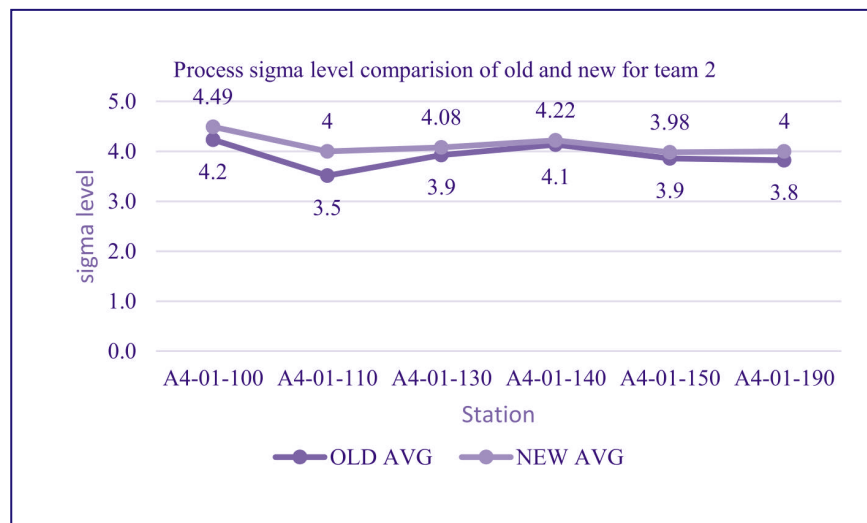
Fig.11. Total Andon calls for team 2 from months December 2016 to March 2017 for both the shifts

Table 12. March 2017 Total calls/Defects for team 2

Station	Month March 2017 Total	Total Engine Produced	Improved Sigma Level	DPMO	Defects %	Yield %
A4-04-110	58	9220	4	6291	0.63	99.37

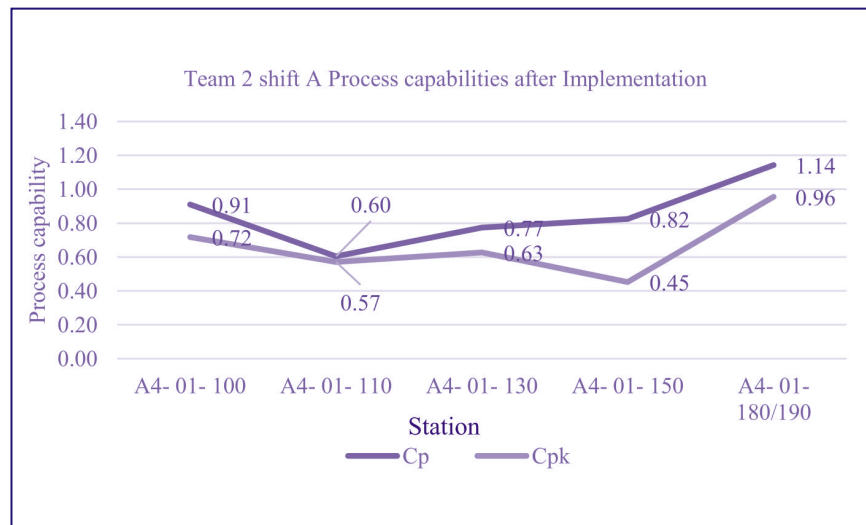
It can be inferred that the execution of the project is successful as the Andon calls are reduced. March Andon calls were 135 and 124 for shift A & B respectively. The station A4-01-110 has seen an increment in production yield from average 97.78% to 99.86 % which very drastic result for the project and project strives for this result. Here it can be seen that on an average sigma level has improved to 4 Sigma. Figure 11 shows positive process

capabilities but not greater than 1. This implies that the station's cycle time completion is almost equal to standard cycle time and lying near to the mean of the cycle time due to the presence of cycle time variation which is present owing to chance causes. The learning curve of an operator plays a very vital role in manual assembly processes.



(a)

The graphical representation of improved process capabilities is shown in above Figure 11 show the result of the six-sigma project in terms improved process capabilities.



(b)

Fig. 12. (a and b) Comparison between before and after project implementation for process sigma level and process capability

Though stations have positive Process capability but not greater than 1 since stoppage of the line is not fully removed. Now the processes are within the given cycle time yet, sometimes a random cycle may not follow the standard procedure due to random causes this is what we can infer from the fig 10.

#### 4. CONCLUSION

Six-Sigma is an effective and efficient way to solve defect generating issues. This review shows that a defect can be considered in terms of non-meeting of cycle time specifications. There are various statistical tools which support six-sigma methodology such as standard deviation, Cp & Cpk. Thus, six-sigma will show a reduction in variation of cycle time and stoppage of an assembly line and will show increment in production output. It is also seen that the success of the six-sigma project is very high. Earlier Cp & Cpk were negative for some station now its improved and positive. It can be observed from the above analysis phase that all stations fall under different sigma level, this project leads the project team to achieve 4 sigma and above level for all the stations which were under study. Before undertaking six-sigma process capabilities were negative which indicates frequently assembly line stops owing to stoppage process capabilities fell towards negative indexes and which can be interpreted as the impossibility of the operations. After executing the six-sigma project all the stations have positive sigma level but not greater than 1 since stoppage of the line is not fully removed. Now the processes are within the given cycle time yet, sometimes a random cycle may not follow the standard procedure due to random causes. The next step or future endeavour would be to achieve process capabilities greater than 1.33. Refine the definition of defect and record as large as a possible dataset to minimize the error. The project team should include more personnel to decrease human efforts. This study was done for only team 2 amongst the five teams and therefore the same methodology can be applied to another team as well to improve the overall performance of the engine assembly line.

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