

# Lean Six Sigma for Quality and Performance Improvement of POH Process of Wagon Wheel CTRB

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## ABSTRACT

Due to high competition in present world, every end user of a product demand their products to be delivered to them on time with good quality. Hence it is an objective of every industry to satisfy their customer requirements. In the long run, this can be achieved by continuous and constant process improvements. Lean Six Sigma is an overall quality improvement approach combining and capitalizing the strengths of Six Sigma and Lean Management improvement programs. In CTRB periodic overhaul, several process steps and workplaces are required for the job, the movement of inventory between the workplaces can be very time consuming unless it is suitably planned. The major areas that need great attention in this system are WIP (work in process), Takt time and process variability. In this study, focus is on the application of lean tools and techniques with their principles coupled with six sigma DMAIC methodology. The objective of this study is to identify the best possible tools and techniques to tackle premature failure of CTRBs whilst in service due to early presence of defects which are closely associated to the POH process. It also discusses the methodology generally adopted, tools and techniques used and benefits obtained. By mapping current state of the POH process and takt time, future state improvement can be done in order to reduce cycle time using Lean tools such as Poke-Yoke, Jidoka, 5S, SMED.

**Keywords :** Periodic Overhaul (POH), Cartridge Tapered Roller Bearings (CTRBs), DMAIC, Lean, Six Sigma

## I. INTRODUCTION

Today, organisations strive for an improved level of process capability and manufacturing quality to achieve the bottom-line objectives of generating a profitable margin and sustainable competitiveness and share in the market. Lean Six Sigma is a quality improvement strategy that helps companies achieve these results. The main portion of this work will be dedicated to a case study analysis of the Periodic Overhaul (POH) process at PratapNagar Railway Wheel and CTRB workshop. Based on a variety of literature and case study review, a Lean Six Sigma model will be developed and implemented at the facility.

To satisfy a growing demand and expectation from customers while coping with increasing product complexity and limited resources, organisations must improve on a continuous basis. As products become more complex, the number of components at the sub-assembly level becomes increasingly large, leading to a higher probability of defective assembly; as a result, there is a drive for superior component quality. Moreover, processes need to have a greater capacity and efficiency to provide a greater throughput to meet requirement.

This project focuses on the approach and application of the Lean Six Sigma methodology. Time has been devoted on literature review and studying a variety

of cases to develop a thorough understanding of the methodology. The knowledge acquired has been applied continuously throughout the course for the work

## II. BACKGROUND

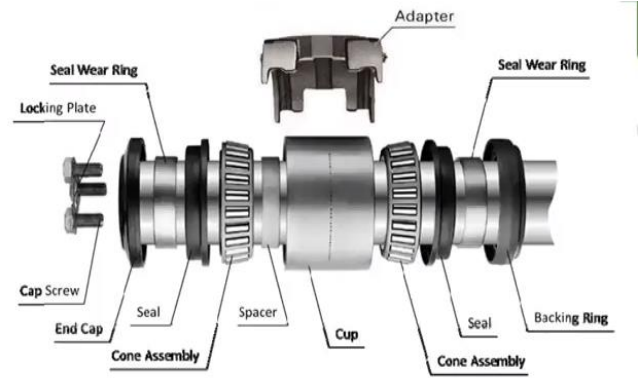
PratapNagar railway workshop is the first state owned railway by ruler of Vadodara and pioneer to lay the first NG railway line between Dabhoi to Miyagaon in 1963. It was then materialized in 1973 when the complete track formation was upgraded. The foundation stone of PratapNagar workshop was laid by his highness Lord Chelmsford, Viceroy and Governor General of India on 25th March 1919.the workshop started in 1922.The workshop is currently being used for repairing and overhaul of coaches and wagons. PratapNagar Workshop consists of eight workshops. In the Wheel CTRB (Cartridge Tapper Roller Bearings) repair shop, POH (Periodic Overhaul) of High Precision E-Type CTRBs for CASNUB 22 HS bogies takes place. Cast Steel CASNUB 22HS-bogie is a type of railway bogie commonly used in freight stock/ wagons.



**Figure 1 : CASNUB 22HS-Bogie**

The main function of CTRB is to support axial and radial forces. The inner and outer ring raceways are segments of cones, the rollers are tapered so that the conical surfaces of the raceways, and the roller axes, if projected, would all meet at a common point on the main axis of the bearing. This geometry makes the motion of the cones remain coaxial resulting with no sliding motion between the raceways and the OD of the rollers. Pairs of tapered roller bearings are

used in wagon wheel bearings where they must cope simultaneously with large vertical and horizontal forces. Tapered roller bearings are commonly used for moderate speed, heavy duty applications where durability is required.



**Figure 2 : EXPANDED VIEW OF CTRB**

The components of CTRB unit are first dismantled in the dismantling unit. Due to long exposure to the environment and working conditions, grease gets hardened. First the unit is dipped in Kerosene oil to soften the grease. Stripping off of softened grease is done through centrifugal action by a Centrifugal Grease Purging (CPG) machine. Final cleaning is done in a tank where the bearing is subjected to kerosene oil and compressed air jet. When clean the components are inspected, checking for some defects. Defective bearings are rejected and the rest are passed on to greasing and assembly where each cone is filled with grease. Under normal circumstances, the predicted fatigue life of CTRBs is 25 years according to NBC Bearings which is the major supplier of bearings to Western Indian Railways (WIR). However, they are often condemned prematurely due to avoidable mistakes in the over hauling process. Accurate determination of the causes of bearing premature rejection must be done to make suitable recommendations for eliminating the cause. In contrast to fatigue life, this premature failure could be caused by incorrect fitting, improper mounting, improper handling, poor lubrication etc.

## PROBLEM STATEMENT

In a 12 week period from August to October 2018, 553 CTRBs were condemned before their set life span. 25% of the bearings were prematurely rejected hence affecting WIR operations as a projected 2.4 Crore (US\$332 000) can be wasted annually.

## AIM

To improve the quality and performance of the POH process of CTRB at PratapNagar Railway Wheel CTRB workshop using lean six sigma.

## OBJECTIVES

- Identify and eliminate causes of premature rejection of CTRBs
- Optimise the performance and quality of the POH process of CTRB.
- Maintain the improved POH process of the Wheel CTRB workshop for sustainability.

## SCOPE

Only investigate the effect of the POH process to the lifespan of CTRB hence:

- Only focus on the eight frequently occurring defects that are associated to the POH process.
- Some other defects that occur due to mechanical or chemical effects whilst the bearing is in service are beyond the scope of this study.
- What happens to the rejected bearings is beyond the scope of this study

## III. FINDINGS OF LITERATURE REVIEW

The DMAIC coupled with Lean techniques can be employed to achieve the efficient use of resources and to minimize non-value added activities in the process. Combining and capitalizing the strengths of Six Sigma and Lean Management improvement

programs. The overall objective being to continuously improve in order to satisfy a growing demand and expectation from customers while coping with increasing product complexity and limited resources. All in all, literature review revealed that Lean Six Sigma implementation can provide a breakthrough improvement in any industry, Railway Industry included.

## IV. RESEARCH GAP

LSS has been used for high quality and performance improvement in numerous industries. There is however no model to measure the success of LSS deployment. There is a need to design a model to measure the impact of LSS implementation on organizational overall performance. The researcher believes that the model will assist new adopters of LSS to anticipate and additionally examine the impact of LSS on their operational overall performance.

## V. METHODOLOGY

### DEFINE PHASE

Define is the first step and decide what is required to be done. It brings a good understanding to everybody the need of project, its impact and implementation procedure. It should be clear what we want to achieve at the end.

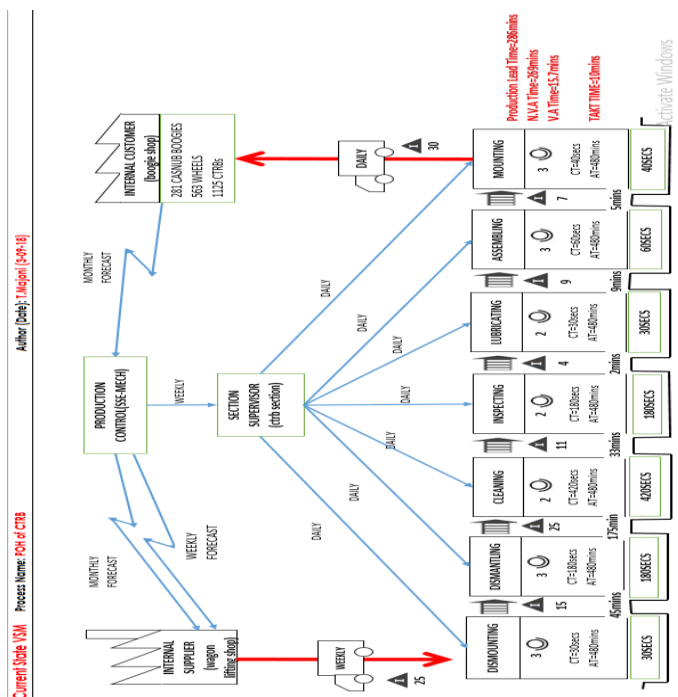
### Project Charter

It is a contract between the project team and its sponsors. It created a shared understanding about the project and the project goal. It mentioned mission, problem statement, possible gains, constraints and assumptions. It also mentioned important persons, key dates during the project and the project status. The charter included reasons for undertaking the project, objectives and constraints of the project.

### Value Stream Mapping (VSM)

Because of unfamiliarity with the POH process at the start of the project, the researcher decided to apply the Value Stream Mapping (VSM) technique to map out the process and identify the main problems of the process. VSM proved to be particularly useful for obtaining a bigger picture of the POH process, it also revealed general problem areas associated with the process.

The VSM captured the entire process, beginning with the dismantling of the CTRBs from the wheels and ending with the mounting of the serviced CTRB on the wheels. The VSM illustrated the physical movement of inventory and information. A time study was done on the entire process and the process cycle time (C/T) and available time (AT) for each process step was derived and listed on the map. The process map was developed based on timing results and observations made on-site at the Wheel and CTRB Workshop facility. Interactions with the workers at the workshop also provided with valuable information.



**Figure 3 : Current Value Stream Map**

A comprehensive understanding of the process was acquired upon completion of the VSM. In the process of developing the map, a list of findings, major areas of focus and concern were identified and summarized as follows:

- The process is running at a slower rate relative to the demand.

$$T_{ct} > T_{kt}$$

This leads to bottlenecks in the process, affecting the overall process performance.

- Due to the difference of  $T_{kt}$  and  $T_{ct}$  there is a high build-up of Work-In-Progress (WIP).
- The non-value-added time of the POH process was found to be 4.4 hours, compared to 15.7 minutes of value-added operations.

These findings narrowed the focus for the researcher and helped to define and pinpoint the problems faced. Based on the observations of the uneven process flow and the high number of WIP level, the POH process was found to be inefficient, accounting for the large proportion of time dominated by non-value added activities. The inefficiency of the process and the unacceptable defects associated to this process imposed a negative effect on the company’s objective of reducing all NVA activities (Integrated Management System Policy 2017 of PratapNagar Workshop). From this analysis, the objectives for the case were set clearly. The goals were to achieve an even, levelled-out flow as well as to improve the performance and quality of the POH process by eliminating non value adding activities that leads to CTRBs being condemned prematurely.

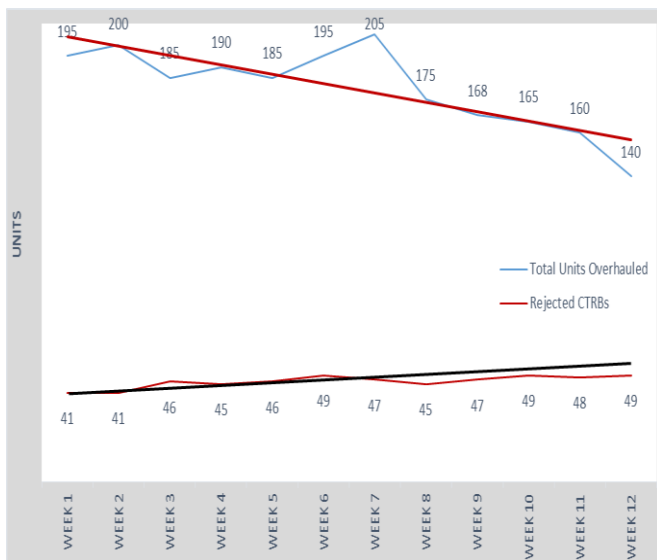
### MEASURE PHASE

The development of the process map and the problem definition from the Define phase enabled the researcher to proceed to the Measure phase. The

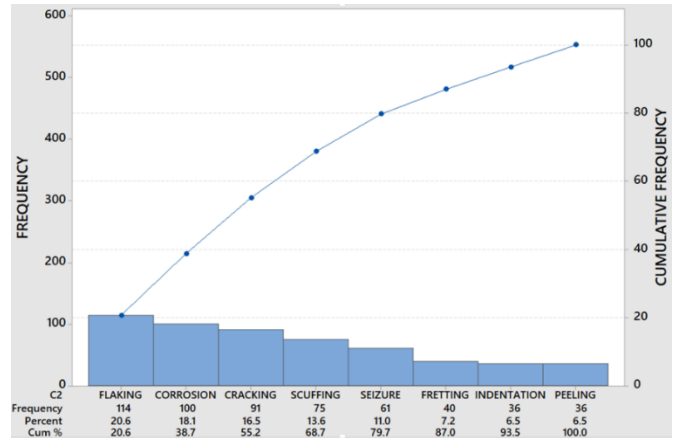
researcher identified from the Define phase that 25% prematurely condemned bearings and process inefficiency were the major problem areas to focus on for the case. In the Measure phase, the goal is to validate and further develop the identified problem areas, as well as to gain a deeper understanding of the problems. To achieve this goal, the researcher continuously collected raw data and conducted further analysis.

**CTRB Rejection Data and Analysis**

To tackle the rejection rate problem, 12 weeks of yield-defect figures for the CTRBs were collected. After a thorough examination of the data, the researcher compiled an overall yield-defect graph and the defect breakdown Pareto chart for the POH process, as shown in Fig 4 and 5 respectively. The poor yield and the high rejection rate as indicated by the high DPMO gave an indication of the incapability and ineffectiveness of POH of CTRBs.



**Figure 4 :** Overall POH process Yield-Defect graph



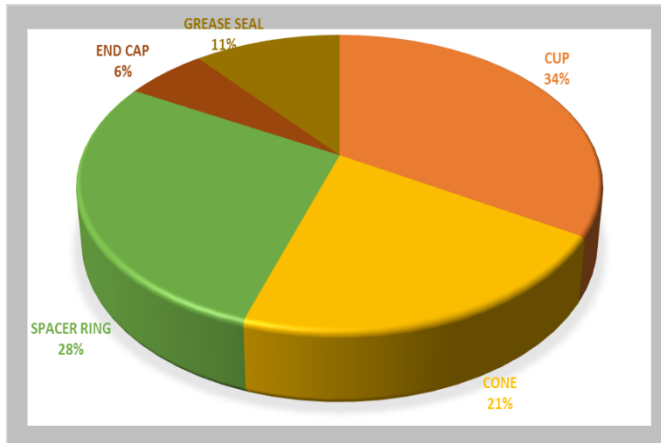
**Figure 5 :** defective chart for rejected CTRBs

Based on the Pareto chart, 55.2% of the condemned bearings were due to flaking, corrosion and cracking. These are the most frequently occurring defects that result in condemnation of the bearings, therefore in consultation with the Management it is agreed upon to apply Lean techniques using Six Sigma to eliminate these defects.

**Data Compilation of CTRB components wise**

Of the components the most critical components are the cup, cone assembly and the spacer ring. CTRB component wise data was collected to identify components which showed the highest frequency of being defective resulting in rejection of the bearing. The chart showed that 83% of the condemned bearings in the period were due to defective cup, spacer ring and cone assembly. This is not by coincidence since flaking, corrosion and cracking (55.2% of the defects) directly attack these components.





**Figure 6 :** CTRB Component Wise Cumulative Rejection

**Sigma Level Calculation**

Sigma level calculation is important to understand capability of POH process. Theoretically, the higher the sigma level the better is the performance. The six sigma level means 3.4 defects per million opportunities. The data collected in this project is discrete data therefore sigma level calculated is using DPMO method.

$$DPMO = \frac{553 \times 1\,000\,000}{8 \times 2160} = 32002.31$$

Current Sigma Level (*DC Montgomery 6<sup>th</sup> edition*):

$$\begin{aligned} \sigma &= 0.8406 + (\sqrt{(29.37 - 2.221 \times \ln[DPMO])}) \\ &= 0.8406 + (\sqrt{(29.37 - 2.221 \times \ln[32002.31])}) \\ &= 3.36 \\ &\approx 3.4 \end{aligned}$$

The Integrated Management System Policy (IMSP 2017) of PratapNagar Workshop emphasise the need for continuous improvement and the need for process capability for sustainability. Therefore even a slight increase in sigma level is a welcome change for WIR.

**ANALYSE PHASE**

The objective is to identify the root cause of POH process variation based on information and data collected in Measure Phase. Additional data is also collected to find out cause of the problem. The data is analysed to check if there are consistent with the problem definition and also to identify the root cause. Three components of the CTRB namely Cup, Cone Assembly and Spacer ring; three types of defects namely Flaking, Corrosion and Cracking are considered for further study to arrive at root cause.

**Material Analysis of CTRBs Critical Components**

Primarily, high carbon chromium steel is used for the spacer rings and rolling elements. NBC bearings are of SUJ2 class of non stainless steel. The chemical composition of the SUJ2 is approximately the same as that of AISI 52100. AISI 52100 bearing steel is a high carbon, chromium containing low alloy steel. AISI 52100 bearing steel is one kind of special steel with features of high wear resistance and rolling fatigue strength etc.

ELEMENT	Fe	Cr	C	Mn	Si	S	P
CONTENT/ %	96.5-97.3	1.3-1.6	0.98-1.1	0.25-0.45	0.15-0.3	≤0.025	≤0.025

**Figure 7 :** AISI 52100 Chemical Composition

The cup is forged, rolled and machined from bearing quality case hardened steel. NBC bearings uses AISI 8620 to make the cup component of the CTRB. AISI 8620 alloy steel is flexible during hardening treatments thus enabling improvement of case/core properties

ELEMENT	Fe	Cr	C	Mn	Si	S	P	Mo	Ni
CONTENT/%	96.8-98	0.4-0.6	0.18-0.23	0.7-0.9	0.15-0.35	≤0.004	≤0.035	0.15-0.35	0.4-0.7

**Figure 8 :** AISI 8620 Chemical Composition

- ✓ AISI 52100 stainless steel resist corrosion twice as much as many grades of steel alloys. Hence it can

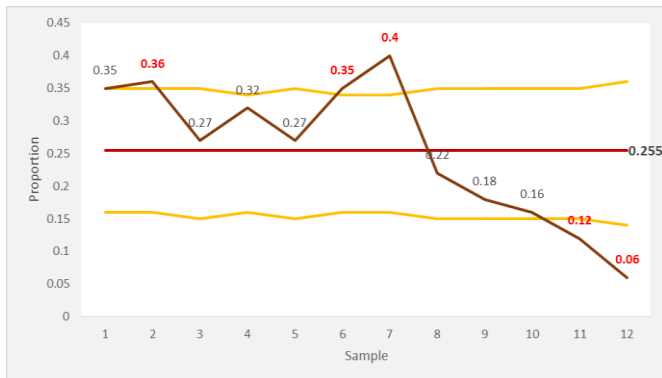
be concluded that the Spacer Ring and Cone Assembly are not prone to oxidation.

- ✓ AISI 8620 can be oxidised due to its relatively low content of Cr. Hence we can conclude that the Cup is relatively more prone to oxidation.

All in all, the cone assembly and spacer ring are affected mainly by flaking and cracking whereas the cup is affected by corrosion, flaking and cracking.

**POH Process Stability**

Control chart is one of the most widely-used tools in the industry for providing an on-line process-monitoring mechanism. As a graphical display, the control chart shows the occurrences of process variability and instability. A specific type of attribute control chart called the p-chart is employed in evaluating the stability of the process. Constructed with the collected yield-defect data for CTRBs



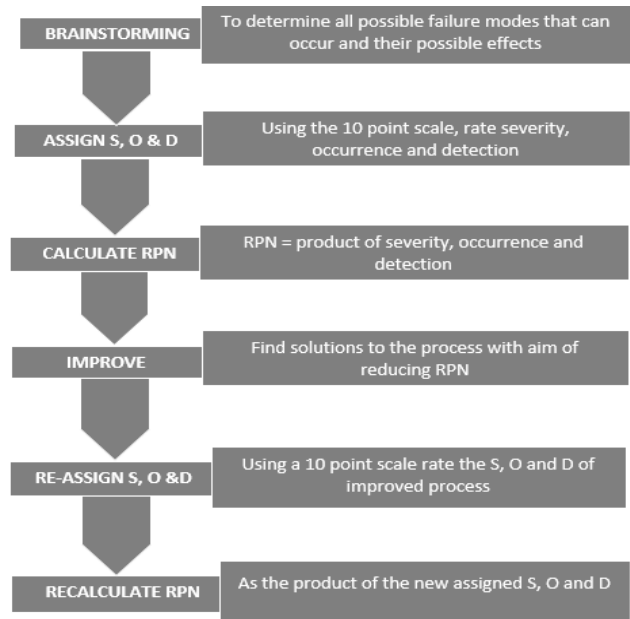
**Figure 9 :** p-chart for rejected CTRBs

From the Control Chart, the average proportion of CTRBs which are rejected prematurely is 0.255. In other words, it is 25.5% of the total bearings that undergo POH process. Highlighted points fell outside of the 3σ limits hence the process is unstable and is out of statistical control.

**Process Failure Mode Effect Analysis (PFMEA)**

When engineers at PratapNagar workshop planned the POH process of CTRBs they envisioned a process which is free of errors due to either chance or

assignable causes. Unfortunately, errors and especially errors propagated when there is involvement of humans can be quite catastrophic and costly. PFMEA is a structured analytical tool used in this study to analyse the POH Process. This is achieved by analysing each process step to identify risks and possible errors from many different sources. In order to achieve the objective of this study it is important to identify errors and their effects for each process step as early as possible.



**Figure 10: PFMEA Methodology**

**IMPROVE PHASE**

In analysis phase the reasons of premature condemnation of CTRBs due to flaking, cracking and corrosion and also the reasons for process variability and inefficiency were identified. The root causes leading to poor quality and performance of the POH process were identified. And th

- Improper Handling
  - Entry of Moisture
  - Poor storage
  - Contamination
  - Excessive mounting/assembly load
  - Imbalanced work flow due to high Tct
- } **HOUSE KEEPING**

In improvement phase solutions are identified and implemented with the help of lean tools.

### 5s

One of the most powerful Lean Tools and a cornerstone of any successful implementation. Lean tool for organising workplace in a clean, efficient and safe manner to enhance productivity, visual management and to ensure the introduction of standardised working resulting in minimised errors in the process. 5S is split into 5 phases, each named after a different Japanese term beginning with the letter “S” i.e.

SEIRI Sort - Separating of the essential from the nonessential items.

SEITON Straighten - Organizing the essential materials a designated place.

SEISO Sweep - Cleaning the work area.

SEIKETSU Standardise - Establishing a system to maintain and make 5S a habit.

SHITSUKE Sustain - Establishing a safe and sanitary work environment.

#### Step 1: Seiri (sort)

In this step the team organised and eliminated unnecessary items within the Workshop. This had to do with JIT, “just what is needed, in the quantity needed, only when needed”. The programme ran under the name “Red Tag Campaign (RTC)” whereby tags were placed on items not required in the shop floor. The RTC is a strategy employed to identify potentially unnecessary items in the shop floor, evaluate their usefulness and treat them appropriately



Figure 11 : Disposed CTRB components

#### Step 2: Seiton (set in order)

Seiton means setting in order the necessary elements so that they are easy to find and use by anyone within the shop floor. The concept of setting in order can be summarised in one sentence as “a place for everything and everything in its place”

**Focus:** Dedicated permanent storage areas for all necessary equipment and items in the shop floor.



Figure 12 : CTRB Components set in order

#### Step 3: Seiso (sweep)

Involves cleaning everything in the shop floor, keeping it clean daily and using cleaning to inspect the workplace and equipment for malfunctions,



leakages etc. Accumulation of dust or file metal shavings can easily lead to contamination of bearing components leading to defects, faulty equipment and even accidents. The causes can be eliminated by appropriate cleaning on a daily basis.

**Focus:** Maintain a clean and safe working conditions thus letting people be responsible for the equipment they are using

#### **Step 4: Seiketsu (standardise)**

No activity would be performed per say, this stage does not refer to an activity, but rather a state or condition. Seiketsu would consist of building a strong set of procedures to maintain the first 3S. In fact, it is the state that exists when the first 3S are properly maintained. When implementing Seiketsu the team made sure to follow the three steps as follows:

- Decide who is in charge of maintaining the needed conditions to maintain the first 3S
- Avoid setbacks by means of integrating daily maintenance.
- Check the level of maintenance

**Focus:** Establish standardised 5S system

When the same problem occurs again and again, it's time to go to the next level: prevention

#### **Step 5: Shitsuke (sustain)**

Basically an extension of Seiketsu (standardise). Shitsuke (sustain) means turning all activities already carried out in previous steps into a habit, that is the fact of maintaining the correct procedures within the shop floor.

**Focus:** Formalise 5S system work area policy

#### **5S Conclusion**

When fully implemented, 5S will help maintain a clean work area leading to reduced contamination, correct ambience to eliminate entry of moisture in grease and bearing components, enable proper storage and handling of all equipment used in the POH process. It will also create positive impression on customer (boogie shop), and increase efficiency in the CTRB Workshop. Not only will employees feel better about where they work, the effect on continuous improvement (IMSP 2017) can lead to less waste, better quality and faster lead times.

#### **POKA-YOKE**

Poka Yoke is a simple technique that is normally a simple and often inexpensive device that prevents defects from being made or highlights a defect so that it is not passed to the next operation. Poka yoke is to be implemented so that there is no excessive loading when assembling and mounting CTRBs on the wheel axle.

The bearing assembly is pushed onto the bearing journal by a hydraulic press. Normally 12-15 tonne/square inch pressure is required to push the bearing to its position. An assembled CTRB weighs 32kg, to prevent misalignment a pilot sleeve is be fastened to the end of the axle to keep the bearing parts together and protect them from damage. The pilot sleeve is removed when the bearing is in its position. If excessive force is applied on the bearing the bearing will be forced to the journal collar and this will lead to premature cracking of the bearing components.

To prevent the bearing to be forced onto the journal collar before the hydraulic presser stops, the pilot sleeve is modified from its original form.

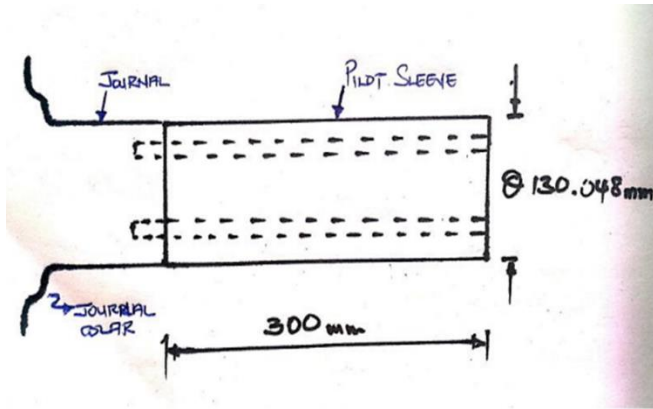


Figure 13 : Original form Pilot Sleeve

A 10mm deep groove is milled on the surface of the sleeve and at the end of the groove a 20mm blind hole is drilled. On the pushing tube which is part of the hydraulic press, a flexible 40mm diameter pin is attached on a hinge such that it moves along the groove on the sleeve, figure 4.12. To stop the motion of the hydraulic press, the hinged pin falls into the drilled hole at the end of the groove. This will alert the operator to retract the hydraulic presser and prevent excessively loading the bearing against the journal collar.

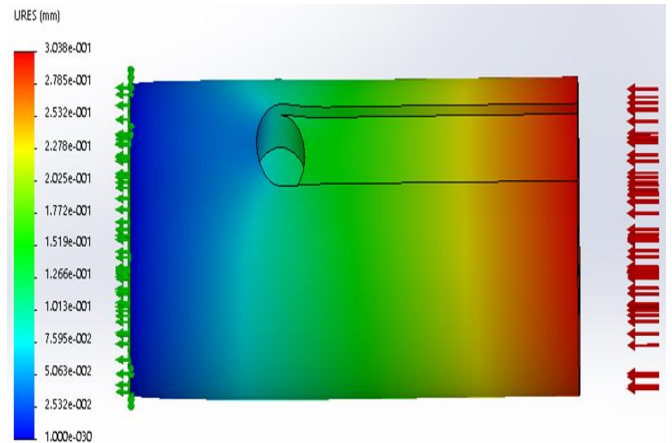
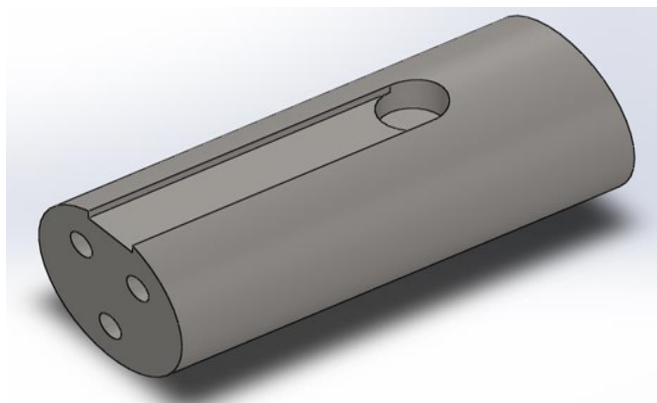


Figure 14 : Modified Pilot Sleeve

With the small modification on the pilot sleeve, the CTRB will be protected from excessive force which pushes it on to the journal collar. This will eliminate premature cracking of the bearing due to excessive loading on mounting. This motion stop Poka-Yoke will take physical action to prevent excessive mounting load hence it is a control Poka-Yoke.

#### SINGLE MINUTE EXCHANGE of DIE (SMED)

SMED is a lean tool which is used to reduce setup time and provide quick changeover. The main aim of SMED is to reduce the time wasted in changeover steps by performing some activities while the process is running, and to integrate and reduce the time required to perform internal tasks. The SMED places the tasks into two categories which are internal and external activities. External activities being those activities performed while the process is running. The internal activities on the other hand are activities which are done while the process is not running.

The POH process is running at a slower rate relative to the demand,  $T_{ct} > T_{kt}$ . This is resulting in bottlenecks in the process affecting process performance, leading to high WIP. The main reason observed why there is such a huge time discrepancy is because of change over time. High change overs are

observed in Dismantling, Cleaning and Mounting steps of the POH process. In the mounting step, change over occurs when switching from axle to axle and also when switching from left wheel to the right wheel of the same axle. To improve the changeover time SMED is employed. The SMED is going to follow the framework:

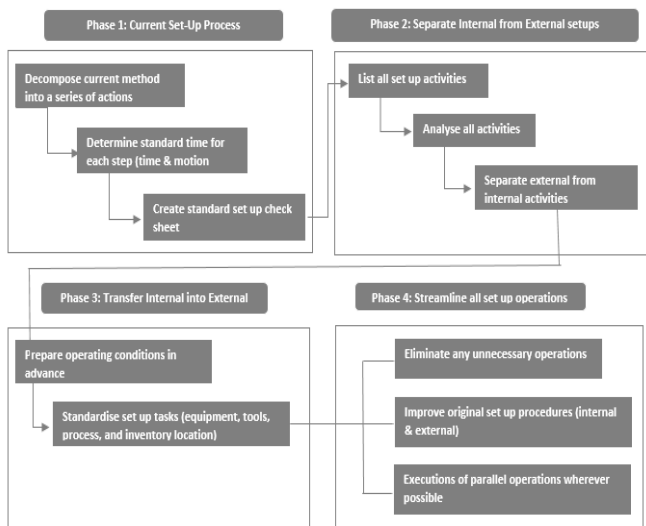


Figure 15 : SMED Framework

Eliminated Task	Reason	Time/s saved	Frequency/day	Total Time saved/s
Creating space to put the bearing units	Due to sustainable 5S in the shop floor, the work space is always clear.	39	3	117
Movement to collect dismantling tools	All frequently used tools are placed within arm's reach in the shop floor,	30	3	90
Loosen the clamp	Use a bench vice that can hold the bearing unit facing sideways rather than the clamp which holds the unit facing upwards	5	30	150
Secure the bearing unit upside down	Use a bench vice that can hold the bearing unit facing sideways rather than the clamp which holds the unit facing upwards	7	30	150
<b>TOTAL TIME SAVED</b>		<b>81</b>		<b>507</b>

Figure 16 : Dismantling Eliminated Activities

Eliminated Task	Reason	Time/s saved	Frequency/day	Total Time saved/s
Remove excess grease from previous shift from the centrifugal grease purging machine	The machine will be cleaned to remove excess grease at the end of each shift. This is in line with the implemented 5S philosophy.	60	1	60
Switch off the machine to remove excess grease	Under the 5S philosophy, the machine will be able to sustain continuous 40second purging without stopping to remove excess grease.	15	30	450
Start the machine for the second purging cycle	Under the 5S philosophy, the machine will be able to sustain continuous 40second purging without stopping to remove excess grease.	20	30	600
<b>TOTAL TIME SAVED</b>		<b>95</b>		<b>1110</b>

Figure 17 : Cleaning Eliminated Activities

Eliminated Task	Reason	Time/s saved	Frequency/day	Total Time saved/s
Collecting of all equipment and material needed for mounting	All frequently used tools are placed within arm's reach in the shop floor.	47	2	94
Check the oil level of the hydraulic presser	The oil will be checked daily after each shift.	4	1	4
<b>TOTAL TIME SAVED</b>		<b>51</b>		<b>98</b>

Figure 18 : Mounting Eliminated Activities

**SMED Conclusion**

	Before SMED	After SMED	Time save
Total Cycle time /shift	437mins (7hrs)	324.5mins (5hrs)	112.5mins (2hrs)

The implementation of SMED saved 227 seconds from the initial 942 seconds (Chart 4.2). This has

reduced  $T_{ct}$  from 15.7 mins to 11 mins. All in all this new  $T_{ct}$  is approx. 60 seconds more than  $T_{kt}$  of 600seconds.

$$T_{ct} \approx T_{kt}$$

**Improve Phase Recommendations**

SN	COMPONENT	EFFECT	Root CAUSES	COUNTER MEASURE
1	Cone, Spacer Ring, Cup	Flaking	Contamination, excessive mounting load, inclined mounting, eccentric mounting,	-Ensure a clean working environment by implementing 5S. -Modify the pilot sleeve (POKA-YOKE)
2	Cone, Spacer Ring, Cup	Cracking	Excessive mounting load	-Modify the pilot sleeve (POKA-YOKE)
3	Cup	Corrosion	Entry of moisture, improper storage conditions, improper handling,	-Ensure a clean working environment and culture by implementing 5S. -PPC should always be worn in the shop floor including hand gloves when handling CTRBs
4	Process Inefficiency	High WIP	Imbalanced work flow, reduced equipment run rate, unnecessary stoppages	-Eliminate unnecessary activities to reduce process set-up times by employing SMED coupled with 5S for clean working area

**Figure 19 : recommended Solutions**

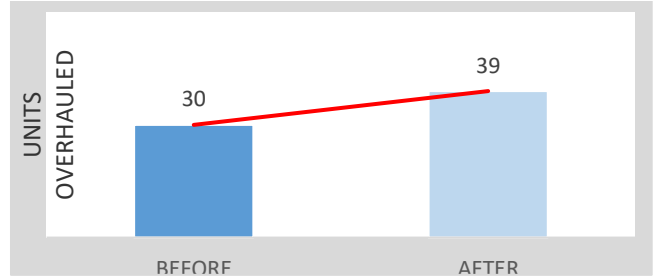
**CONTROL PHASE**

Now the bigger question is, how are we going to sustain our improvements? Now that the process problems are fixed and improvements have been recommended, the team must ensure that the updated process maintains the gains. Focus is on creating a monitoring plan to continue measuring the success of the updated process and developing a response plan in case there is a dip in performance. Once in place the team hands over all these plans to the process owner for ongoing maintenance.

**Performance Monitoring**

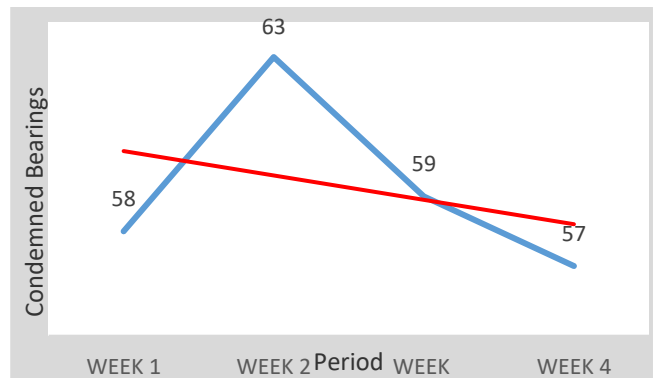
There has been a significant increase in the number of units overhauled per shift. Previously, 30 bearings would undergo POH process per shift but now 39 bearings are overhauled per shift fig 20. However as expected, the condemned bearings are still as before i.e. 25%. This is because the bearings overhauled now were once overhauled before improvements were made. This is however projected to reduce to 12%

after a period of 24-36 months from February 2019. Fig 21 show the number of bearings condemned in March 2019 after some process improvements were made.



**Figure 20 : CTRBs overhauled per shift**

DAY	WEEK 1	WEEK 2	WEEK 3	WEEK 4
MON	6	8	9	7
TUES	10	11	14	12
WED	10	13	12	9
THUR	9	10	-	11
FRI	12	12	13	10
SAT	11	9	11	8
<b>TOTAL rejected</b>	58	63	59	57
<b>TOTAL overhauled</b>	247	244	211	244
<b>% Rejected</b>	23.48%	25.82%	27.96%	23.36%



**Figure 21 : Condemned bearings in March 2019**

After this data collection, overall yield-defect graph for the POH process, as shown below was created.

The trend lines are almost parallel relative to fig 4 mainly due to the increase in the number of units overhauled per shift.

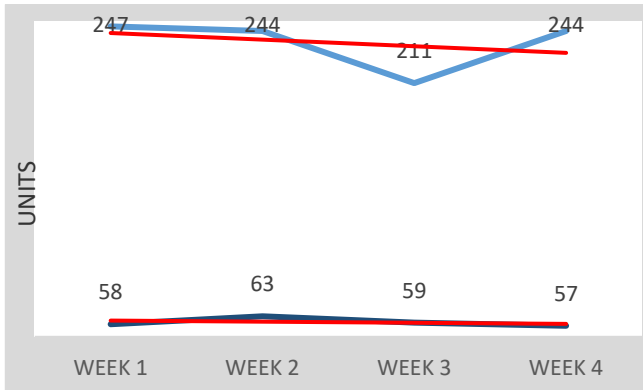


Figure 22 : Overall yield-defect graph for March 2019

Due to limited time to monitor the changes in the process, the changes in DPMO and sigma levels will be very small. The projection is that after 24-36 months from implementation the changes will be big

$$DPMO = \frac{237 \times 1\,000\,000}{8 \times 946} = 30\,306$$

$$\sigma = 0.8406$$

$$+ (\sqrt{(29.37 - 2.221 \times \ln[DPMO])})$$

$$= 0.8406 +$$

$$(\sqrt{(29.37 - 2.221 \times \ln[30\,306])})$$

$$= 3.48$$

$$\approx 3.5$$

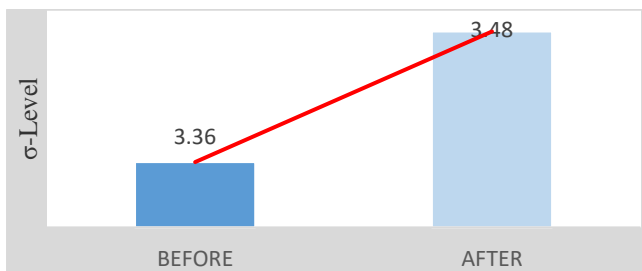


Figure 23 : Sigma Level Changes

DPMO has reduced by 5.3% which indicate that the performance of the POH process of CTRBs has improved. Percentage improvement of sigma level is 0.6%. These percentages are relatively small because

of some limitations already highlighted. Moreover some of the solutions are not yet implemented. Further increase in sigma level needs implementation of all recommended solutions.

### Control Plan

Organisations are good at rallying around chronic problems and finding solutions. But the long term discipline in sustaining solutions is a totally different story, all too often a process will slowly return to its original state as the path of least resistance takes control. This is where control plans play a vital role in sustaining process improvements over the long run. A guide to continued monitoring of the process and the response plan for each of the measures being monitored. It describe the CTQ characteristics of the POH process. Through this system of monitoring and control VOB and VOC will be met and the process variations will be reduced. This plan is not a replacement of detailed operator instructions in the form of work instruction or standard operating procedures.

STEP	EQUIPMENT	CTQ	SPECS	SIZE	FREQ	RESPONSE
DISMOUNTING	Hydraulic extractor	time	<49.5min s/shift	Daily yield	All units	With help of wagon lifting shop keep exact records of reasons of step delays.
DISMANTLING	Hydraulic press	time	<117mins /shift	Daily yield	All units	If delayed request for more personnel to avoid WIP build-up.
CLEANING	Kerosene tank	time	<165mins /shift	Daily yield	All units	Keep exact records of delays
	CP Machine	time		Daily yield	All units	Keep records of delays and maintenance especially of CP Machine
LUBRICATION	Lubricating gun	time	<165mins /shift	Daily yield	All units	If delayed, only lubricate what can be assembled in that same shift
ASSEMBLY	Assembly presser	time	<19.5min s/shift	Daily yield	All units	Keep exact records of the reasons for assembly delays if they occur
MOUNTING	Hydraulic press	time	<110mins /shift	Daily yield	All units	To avoid WIP, get the daily demand from boogie shop and keep exact records of delays

Figure 24 : Control Plan

As mentioned, in this phase, performance monitoring after implementation of some recommended solutions was done in March 2019 i.e. for 4 weeks.



Performance monitoring indicated that recommended solutions are effective and resulted in improvement if fully implemented. Therefore the recommended solutions were standardised and documented fig 24. With this the dissertation study was closed.

## VI. CONCLUSION

The DMAIC approach can be followed to identify the causes of different industrial problems, measure the process capability, analyse the potential causes of demoted quality, implement improvements and control the process such that long-term improvements can be sustained. Lean tools and techniques can be employed to achieve the efficient use of resources and to minimize non-value added activities in the process. Combining and capitalizing the strengths of Six Sigma and Lean Management improvement programs. The overall objective being to continuously improve in order to satisfy a growing demand and expectation from customers while coping with increasing product complexity and limited resources.

All in all it can be concluded that the following can be achieved by implementing LSS:

- **PROCESS CAPABILITY:** the uniformity of the process
- **SUSTAINABILITY:** the economically sound processes that minimise negative environmental impacts whilst conserving energy and natural resources.
- **COMPETITIVENESS** - avoiding penalties for non-compliance products, lowering costs of production, increasing productivity, and consequently reduced amount of WIP
- **CUSTOMER SATISFACTION** - increased customer satisfaction due to increased timeliness and reduced lead time.

- **EMPLOYEE MORALE-** increased comfort and better organization, lack of overtime,
- **DEMING'S 5TH POINT OF QUALITY:** continuously improve the process of production to minimise waste and improve on productivity and efficiency.
- **OTHER-** the possibility of taking more orders during a prescribed period.

All in all, Lean Six Sigma implementation can provide a breakthrough improvement in any industry, Railway Industry included.

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