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DEVELOPMENT OF LEAN LINE TRANSFORMATION TO REDUCE GAS TURBINE PARTS REPAIR LEAD TIME (STUDY CASE FOR PT XYZ)

Wakid Mahmudi[a] & Gatot Yudoko[b]
ab Bandung Institute of Technology, Bandung, Indonesia.
Corresponding email: wakid_mahmudi@sbm-itb.ac.id

Abstract

As the gas turbine market business will grow significantly by 6.2% from 2022 to 2030 globally and will grow 4.9% per annum from 2021 until 2030 in Indonesia, PT XYZ as a Gas Turbine repair center of excellence shall improve the productivity to serve local and global market. On the other hand, the global political situation is quite dynamic and involving tension between US and China, since PT XYZ is a part of US company, the global direction is to move some of the volume from China repair shop to Indonesia repair shop by 13K by utilizing the existing facilities. PT XYZ experienced high repair lead time due to the waste of the repair process, the existing repair processes were still in batch instead of single piece flow, the repair stations were scattered in the shop and required manpower travelling back and forth from one place to another in a significant distance, the operator workloads were unbalance and lead into bottle neck and long waiting in the process. The lean principles to be applied to tackle the issues that is to identify the root cause of the issue and to define the sequence of the improvement step. The lean tools to identify the root causes of the issue are value stream mapping, drill down trees, spaghetti chart and fishbone, hence the tools to define the sequence of improvement process are Takt time identification, Yamazumi levelling, 7 Ways Layout, layout development, improvement process and run the new repair line with a single piece flow process. The result of the improvement is the repair process runs in a single piece flow instead of batch, the load of operator is also balanced, the layout is optimized, and the repair waste reduced as well, such as waiting, inventory and traveling. On the top of that the lead time was reduced by 35% per set with repair hours saving by 15K yearly or USD 0.3M. Hence, PT XYZ are confident to accept the global challenge including additional volume 13K from China

Keywords: Gas Turbine, Lean Transformation, Takt Time, Lead Time, Yamazumi Levelling.

1. Introduction and Purpose

The demand of power industry is significantly increasing year over year, one of the segments that continuously increased is the industrial gas turbine power plant. Gas turbine business is prospecting and promising. The economics of power generation by the gas turbine is proving more attractive in all parts of the world due to its low capital cost and high reliability and flexibility in operation (Saif M, 2022). it is also free from high vibration and high ability to produce large power of electricity since it operates by converting a natural gas or liquid fuel into mechanical energy to drive generator to produce the electricity.

The global demand of gas turbine is expected to expand at a compound annual grow rate (CAGR) of 6.2% from 2022 to 2030 (GVR-2-68038-209-9). In terms of country level, The Energy and Mineral Resources Ministry (ESDM) issued the newest electricity supply business plan (RUPTL) in 2022, it is projected that the electricity demand will grow 4.9% per annum from 2021 until 2030 with new gas turbine power plant new install base will grow until 5.7 GW in 2030 (RUPTL, 2022). Therefore, it will become an opportunity for PT XYZ as a global repair service center of excellent (COE) that currently serve 85% global market and 15% local Indonesia market to drive further improvement in terms of repair productivity and capability.

On the other hand, the global political situation is dynamic and involving tension between US and China, since PT XYZ is under US company, the global direction is to move some of the volume from China repair shop to PT XYZ as Indonesian repair shop by 13K by utilizing the existing facilities. In Addition, PT XYZ experienced high repair lead time due to a lot of wastes in the existing repair process flow, the repair processes of gas turbine parts were still in batch instead of single piece flow, the repair stations were scattered in the shop within the area 2500m2 and it was required manpower to travel from one station to another back and forth back and forth in a significant distance, the operator workloads were unbalanced as well and drive into long waiting process

2. Literature Review

Lean transformation plays important role to reduce lead time, (Prajapati et al., 2015) defined lean as a set of tools and practices that aims for the continuous elimination of all waste in the production process. The main benefits of this are lower production costs, improved output and shorter production lead times. Since the basic concept of the lean is to eliminate the waste, it is important to understand whether any waste on the existing business process, (Ohno, 1998) identified 7 types of waste commonly occur, that is overproduction, inventories, unnecessary processing, non-required motions, defects, waiting and transportation. According to the book “Lean Thinking” by Womack and Jones, the approach of lean concept is to deliver the result from a general perspective by implementing lean concept from a functional level to the business level. Therefore, (Womack and Jones, 1996) introduced five principles in lean thinking: define value from the customer perspective, Identify the value streams, make the value flow, implement pull-based production, and strive for perfection continuously.

Another terms to be considered to drive the lean improvement is Mura (Unevenness), According to (Pienkowski, 2014), Mura means variation or unevenness. It refers to waste of unevenness in production volume. Variation in production scheduling and uneven production workload and pace of work. Thus, if the Mura is uncontrolled properly it will lead into big challenges to achieve the just-in-time system since the one of main causes of Mura is the batch logic (Pienkowski, 2014)

There are several basic tools to assists in driving continuous improvement process and enhances the change of attitude of employees. (Dale, G. et al, 2003) explained that tools and techniques are used to “aid quality planning, listen to the ‘voices’ of the customer, capture data, control processes, make improvements, solve problems, and improve people.” Some of the tools that will be used to identify the root cause of the problems are:

Value Stream Mapping is a tool to visualize the overall repair process flow including the waste inside. Thus, (Womack et al., 1990) defined value stream as the set of all specific actions required to bring a specific product through the three critical management tasks of a business unit, problem solving task, information management task and physical transformation task. According to Erlach (2013) the analysis of processes should follow a specific order. The order shall start through the identification of value-added process to continue to expand further until the supplier

Spaghetti Chart is a tool to visualize and analyze the operator movement in production line. (Kanaganayagam et al., 2015) stated that it is a method to view the movement of the object in the system with help of a line. In addition, It's a graphical representation of travel distance and travel patterns (Wedgwood, 2006)

Cycle time chart is a tool to identify operator work balance, it is also a tool to illustrate balance of time between process steps; weaker on overall cycle time (George, 2005).

Hence, the tools that will be used as the kaizen improvement as follow

Gage Repeatability and Reproducibility (Gage R & R) is a methodology used to define the amount of variation in the measurement data due to the measurement system, (Kumar, et al., 2006) also mentioned that a gauge repeatability and reproducibility (R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether it was accurate or not

Takt Time: Takt time represents the average pace of sales over a specific time period. It defines the time available to produce one part [Shingo, 1989]. It is the overall available production time in a chosen time interval divided by the overall forecasted customer demand for the time interval. In addition, the total manpower that is needed in the line is total cycle time divided by the Takt time

Yamazumi Levelling: Yamazumi is a chart in Japanese language means "staked up", the chart is to show how many manpower needs on doing working process. (Arianti et al., 2020) mentioned that the bar chart shows the total cycle time for each operator when carrying out their processes in the production flow. Thus, the chart will be staked up based on the cycle time of the process compared to takt time (Afriyanti, 2020)

7 Ways Layout: a 7 ways concept is structured approach to enable the team to evaluate the existing layout and generate idea to improve the existing layout by considering those four fundamental layouts, The 7 Ways method forces a team to manage creativity by thinking beyond the obvious solutions and evaluating option that available. In addition (Kyle Kohlman, 2013) mentioned that the goal of a lean layout is to increase efficiency and allow for flexibility in production process

Process Capability: Process Capability is a statistical measurement of a process's ability to produce parts within specified limits on a consistent basis. (Wooluru, 2014) mentioned that Process capability study is a method of combining the statistical tools developed from the normal curve and control charts with good engineering judgment to interpret and analyze the data representing a process

Hypothesis Test: is a tentative assertion or a formal statement of theory (testable or refutable) that shows how two or more variables are expected to relate to one another (Søren Johansen, 1991). Thus, hypothesis test is required as evidence to prove whether any improvement post project. On the other hand, it is also an assumption about a population parameter. This assumption may or may not be true.

3. Research Methodology

The methodology of this research is categorized into three sections, the business issue exploration, current condition, proposal Improvement, and the implementation of the improvement.

Business issue exploration: the porpose of this section is to explore what is the issue, including the gap of the existing condition compared to target achevement, some of the lean tools to be utilized to find the root cause of the issues.

Proposal improvement: After identify the issue, the next action is to propose the improvement method to come up with the strategy and actions to overcome the issue through the implementation of the lean principles

The implementation of the improvement: the purpose of this section is to perform the actions through the implementation of the improvement proposal, and to confirm to get the benefit post improvement process

4. Problem Identification and Scope

The gas turbine demand is projected to increase drastically in the next upcoming years. In addition, as a result of high political tension between US and China since PT XYZ is multinational company under American conglomerate company, the company's direction is to move 13K of gas turbine repair volume for combustion liner from China shop into Indonesia shop, moreover the Indonesia shop (PT XYZ) will gain better cost since the billing rate and overhead cost per hours pretty much lower compare to China shop, thus PT XYZ is required to prepare repair capacity to accommodate rapid volume increment from China Shop by reducing the existing repair lead time, change the process from flow from Batch into single piece flow and define the proper process, As a summary the research purpose is to identify the three problem, What is the existing condition in terms of repair lead time? What is the proposed solution to reduce lead time? And What is the result in terms of lead time post improvement?

The research is limited to the lean model line development in PT XYZ as an official repair shop of American Gas Turbine Manufacturer, the gas turbine parts already dismantled at customer site and ready to repair at repair shop. The gas turbine repair scope in this research is focused only for gas turbine part, that is combustion liner components Frame 5, 6B, 7E and 9E including DLN (Dry Low NOx) configuration

5. Research Approach

The quantitative approach will be applied for this research by collecting the repair lead time data. The pre improvement data characteristic will be analyzed and compared to the improvement target to see the gap by utilizing the statistical method. Furthermore, the lead time of post improvement data will be collected and compared with the pre improvement data, the statistical hypothesis test to be utilized as well to confirm whether any improvement achieved after the project implemented

6. Data Collection

The main data that will be collected for this research Is lead time data, the lead time will be collected before and after the improvement project. Prior to collect the data it is important to identify gage R&R to define the amount of variation in the measurement data due to the measurement system. PT XYZ has two type of measurement system, Kronos System and Manual measurement

Table 1 Gage R&R Data

Part	Kronos	Stopwatch	Range
1	31.8	32.1	0.3
2	32.1	32.6	0.4
3	32.5	32.1	0.4
4	32.2	32.5	0.2
5	32.6	32.4	0.1
Sume of Range			1.5
Ave of Range			0.3
		Remark	
Tolerance	1,970	USL 2000, LSL 30	
Gage Error (GRR)	1.34	5.15*R/1.191	
%R&R	6.8%	100*(R&R/Tolerance)	

Gage Error is calculated by multiplying the average range by a constant value (4.320). The constant value is derived from the ratio 5.15/d2, where d2 is 1.191 for 5 parts and 2 operators, while 5.15 STD represent 99% confidence level for a normal distribution. Since the result is 6.8% (less than 10%), it is concluded that the measurement through Kronos and Manually using stopwatch is acceptable and effective to drive process improvement according to the Automotive Industry Action Group (AIAG).

The process capability needs to be verified by defining the target as the numbers that is aimed to achieve post project improvement to accommodate the volume increment and volume transfer from China. To get more safety factor, it is targeted to get 35% from the existing data (207hrs) while USL (Upper Specification Limit) and LSL (Lower Specification Limit) is a + 5% deviation from target (USL=217hrs, LSL =197hrs), while the pre project improvement lead time is 318, the stability check for the data are as follow

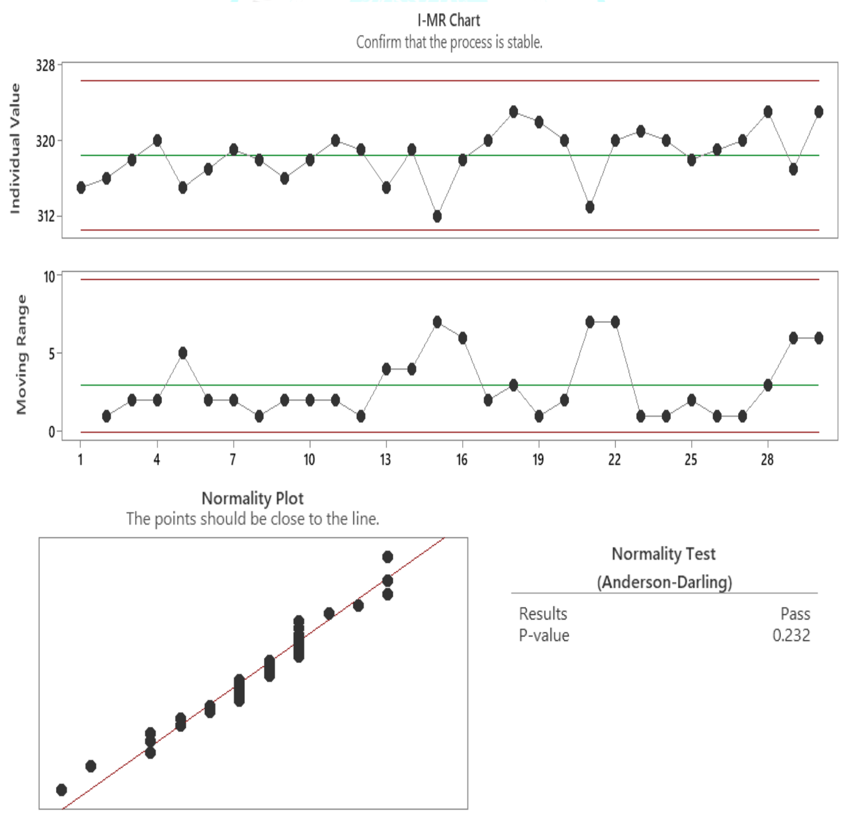


Figure 1 Stability and Normality Chart

According to I-MR chart above, it is confirmed that there are no data that outside red line for both individual and moving range, we may conclude that the data are stable, and no outlier found during the measurement. In terms of the normality test result, it is concluded that the data is normal since the P value is more than 0.005. the existing process capability as shown on below chart. The process capability was checked as well to identify whether the existing data is acceptable compared to the target. According to result, the process means differs significantly from target ($P<0.05$), the defect rate is 100% which estimates the percentage of lead time from the existing process that are outside the specification limits. Thus, the process improvement must be done to bring the existing process capability within the specific limit

7. Analysis

The analysis was conducted to identify what is causing the high repair lead time. According to the root cause and pareto analysis that was conducted, there are top three items that lead into the high lead time, the batch repair process, the repair station that scattered in the repair workshop and unbalance operator workload. The VSM is used to visualize the existing gas turbine part repair process, and according to below VSM, PT XYZ experienced the high process lead time due to waiting on each of the repair process, this waiting process is caused by the batch repair process instead of single piece flow repair

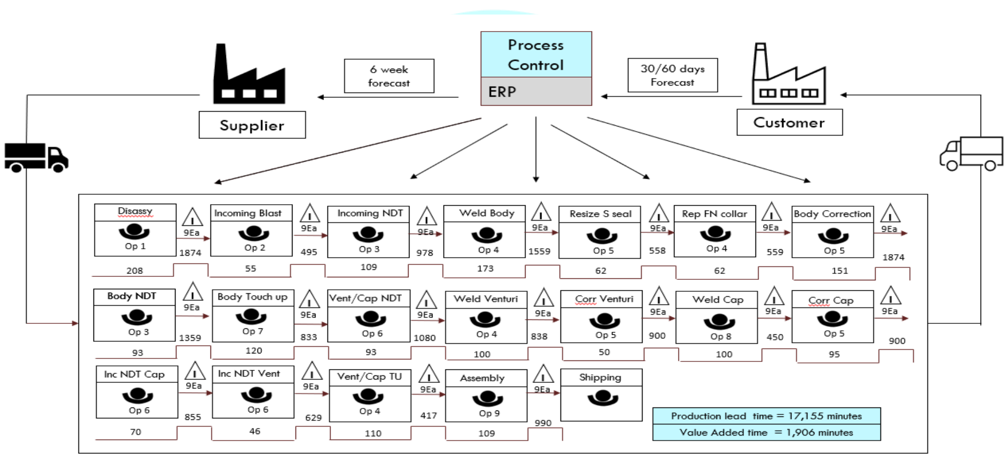


Figure 2 Gas Turbine Parts Repair VSM

Beside the waste due to waiting process, the spaghetti chart analysis also shows that the existing layout is scattered in some places in workstation, so that the operator required to travelling back and forth in long distance from one station to other station. In Addition, the cycle time chart analysis shows that the operator workload is not balanced, Operators 4 and 5 have over workload compared to the other operator, while operator 2 is the lowest workload. Hence, the list items below are required to improve lead time of repair process and eliminate the wastes

Takt time and manpower identification: To identify the takt target according to repair demand and repair available time and to define required manpower that is needed in the new repair line.

Yamazumi levelling: To level load manpower task according to the takt time vs cycle time

Layout improvement: To explore the new layout option including pro and cons of each layout option through 7 ways layout and choose the best one, then translating it into the actual layout in repair line and run the repair process in new repair line and record the repair cycle time improvement

8. Business Solution

8.1 Takt and Power Identification

In order to balance the load of operator, it is required to calculate the takt time of the existing process, Takt time is overall available production time in a chosen time interval divided by the forecasted customer demand for the time interval The forecasted demand for 2023 is received from optimization team is 1,124 pieces in 2023, while the available time is the total minutes that is available in 2023 excluding holiday and vacation, since PT XYZ is running in 2 shifts, the available time will be 246,510 minutes in 2023 so the calculation is

$$Takt\ time = \frac{Available Time}{Forecast\ demand} = \frac{246{,}510\ min/year}{1{,}124\ pcs/year} = 219\ min/pcs$$

$$Manpower = \frac{Total\ Cycle\ Time}{Takt\ time} = \frac{1906\ min/pcs}{219\ min/pcs} = 9\ people$$

8.2 Yamazumi Levelling

Yamazumi plays important role to balance to workload of each operator. Since the operator workload unbalanced, it is needed to perform levelling by utilizing Yamazumi concept to balance the operator workload to achieve the Takt time target, the levelling is expected to be done at the same operator type, the operator types can be categorized as three types

Table 2 Operator Type and Task

Operator Type	Task	Operator number
Fitter	To perform disassemble, assemble, blasting, and dimensional correction	Operator 1, Operator 2, Operator 5, Operator 8, Operator 9
Inspector	To perform NDT inspection and dimensional inspection	Operator 3, Operator 6
Welder	To perform weld repair and touch up for liner body, cap, and venturi	Operator 4, Operator 7

The table above shows that each of the operator has different kind of type and expertise, it is suggested that the workload levelling shall be done at the same type otherwise additional training and OJT are required, the levelling scheme by considering the similarity of operator type is shown on the following chart

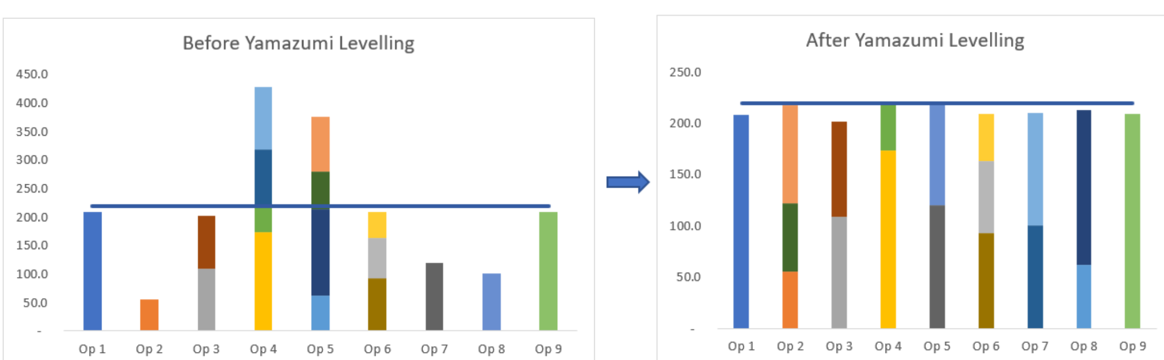


Figure 3 Yamazumi Levelling of Operator Workload

The graph after levelling shows that the workload of each operator can meet the takt time that already set at the beginning by performing the adjustment on operator's task

8.3 Develop Layout

During layout development, it is discussed among stakeholder through brainstorming method and initiate the team to manage creativity by thinking beyond the obvious solutions and evaluating options that available. Thus, there are some fundamental considerations to implement new layout in working area

- Support Single piece flow: The layout shall accommodate single piece flow is to avoid batch process by minimizing the inventories and time required to complete the task
- Enable developing multi skilled employees: some of the operators may work multitasking to balance the workload, the layout shall support the employee who perform multitasking without disrupting the process flow
- Minimize return trips: the good layout shall avoid back and forth work for the operators during the process to smooth the lean line
- Support visual control: the layout shall accommodate visual control to ensure the sustainability of work performed in the line

The team came up with four layout proposal, then it is required to choose the best among those four layouts by considering the pro and cons of each proposal. Stakeholders conducted further meeting to select the final layout to implement in PT. XYZ, below table shows pro and cons of each layout selection

Table 3 Pro vs Cons of each Layout Option

Layout	Pro	Cons
Option 1	• Have bigger space in the middle for easier parts to maneuverer	• Station 6 and 7 are too close to the wall • Difficult to transfer part from station 6 to station 7, operator need to turn around backward
Option 2	• Part transfer from station 6 to 7 not too far • Operator 3 travel from station 3 to 7 is closer • Better part transfer from station 7 to 8	• Station 6 is too close to the wall • Difficult to transfer part from station 6 to station 7, operator need to turn around backward
Option 3	• Better parts transfer from each station • Ideal U shape model • Clear in/out area	• Station 8 to 15 a bit tight, but still can easily manoeuvre with gap 0.5m
Option 4	• Create better room for Station 8 to 14 • Better parts transfer from each station	• In and out area at the same location (between station 15 and station 1), cannot provide clear demarcation of in/out parts

According to the above pro and cons, the option 3 provide best result compared to others, thus stakeholder decided to go with the option number 3 due to the better benefit to eliminate waste and less cons, so layout is fit to be implemented in PT XYZ and align with Yamazumi levelling as well

The final step of lean line development is to translate the lean concept into the line creation according to layout option 3. Thus, as a part of lean transformation, the existing welding booth will be demolished to be replaced with open space welding booth to minimize the space and re-arrange electricity and gas supply in existing line. Furthermore, the 2D paper layout is put on the floor to ensure that the layout concept is fit into actual size prior to installing the new station.

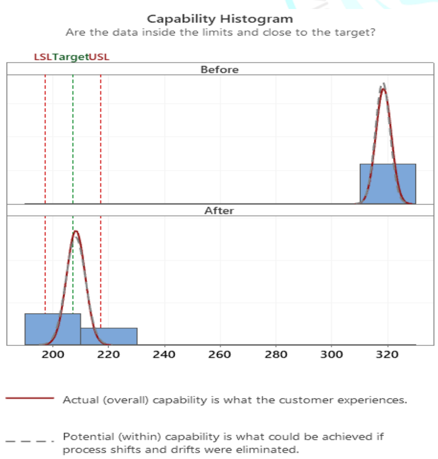
After all dimension confirmed, the last step is to paint the floor and wall to make it more visible and shinier and install the frame of the stations with open space concept for welding, fitting, and inspection. This station is installed in the place that already been mapped and set better 5s with point of use (POU) of tools and consumables

9. Result

The Lead time data of post improvement is within the acceptance range (208 hrs) with target 207 hrs and upper specific limit (USL = 217 hrs) and lower spec limit (LSL =197 hrs). The hypothesis test will be performed as further assessment to prove the improvement post project. According to hypothesis test, the preliminary assumption will be no different between pre and post project (H0 = H1) until it is verified the P value, if P value less than 0.05, the assumption will be rejected, and it can be concluded that (H0 ≠ H1)

Since the data is continuous Y and discrete X, it is used 2 sample t-Test as a purpose to see the different in centering. The result of P value is 0.001 or less than 0.05, the assumption of no different between pre and post improvement (H0 = H1) is rejected and to accept the conclusion with 95% confident level that there is significant different of pre and post project improvement (H0 ≠ H1) which resulted that the mean of post improvement data is lower than the mean pre project improvement.

On the other hand, the statistical result shows that the data are stable for both pre and post improvement either individual range or moving range, even though the post improvement have a lower range of data result. The normality test for both pre and post improvement project are passed the test as well since the P value is higher than 0.05.



Process Characterization

	Before	After	Change
Total N	30	17	
Subgroup size	1	1	
Mean	318.47	208.24	-110.23
StDev(overall)	2.7759	3.3453	0.56940
StDev(within)	2.6290	3.5461	0.91709

Capability Statistics

	Before	After	Change
Actual (overall)			
Pp	1.20	1.00	-0.20
Ppk	-12.18	0.87	13.06
Z.Bench	*	2.59	*
% Out of spec (obs)	100.00	0.00	-100.00
% Out of spec (exp)	100.00	0.48	-99.52
PPM (DPMO) (obs)	1000000	0	-1000000
PPM (DPMO) (exp)	1000000	4788	-995212
Potential (within)			
Cp	1.27	0.94	-0.33
Cpk	-12.87	0.82	13.69
Z.Bench	*	2.43	*
% Out of spec (exp)	100.00	0.75	-99.25
PPM (DPMO) (exp)	1000000	7491	-992509

Figure 4 Process Capability Comparison Pre and Post Improvement

In terms of process capability, the above chart shows that it is 95% confident that there is significant different of pre improvement compared to post improvement, the percentage of the lead time that out of spec is reduced from 100% to 0.48% and followed by the defect per million opportunity was reduced from 1,000,000 DPMO to 4,788 DPMO. Thus, the summary of projected saving for all components as shown below

Table 4 Overall Project Saving

Components	Before Project	After Project	Saved hr/set	Volume FY23	Total saved hrs/year	Saving (BR $20)
F5 CL	283	184	98.9	7	693.4	13,851.8
6B CL STD	318	208	109.8	31	3,402.7	68,054.1
6B CL DLN	431	280	150.9	8	1,206.8	24,150.6
7E CL DLN	516	335	180.6	23	4,153.8	83,076.6
9E CL STD	510	333	177.2	25	4,462.5	88,617.6
9E CL DLN	637	414	222.2	6	1,337.7	26,668.2
Overall Saving			939.7 hrs/set (35%)		14,528.1	290,561.2
					~ 15K	~ $0.3M

The above table shows that the overall saving for lead time reduction project by implementing lean line transformation will be 15K (35%) yearly, thus it is also concluded that PT XYZ will be ready to cover the additional volume from China that was estimated around 13K in FY23.

10. Conclusion

The study to develop lean line transformation of gas turbine repair in PT XYZ has been conducted by implementing lean principles and methodology. The purpose of the research is to prepare the shop readiness to receive 13K additional volume transfer from China shop by verifying three questioned items, the existing PT XYZ conditions in terms of repair process flow and lead time, the proposed solution, and sequence of the solution method to achieve the lead time target.

The repair flow of pre project improvement is in batch condition, each of the repair station is scattered everywhere in the shop with a lot of back and forth that lead into traveling waste. In addition, the load of operator is unbalance as well and lead into bottle neck and waiting in the process.

The proposed solution for this issue is to apply some lean methodology, some of the tools were used such as value stream mapping, drill down trees, spaghetti chart and fishbone to identify the root cause of the existing high lead time issue.

The sequence of resolution method also implemented through implementation of lean principles as well such as Takt time identification, Yamazumi levelling, 7 Ways layouting to implement new layout, Improving the process and run the new repair line with a single piece flow process

The result of this new gas turbine repair line is currently the process runs in a single piece flow instead of batch, the load of operator is also balanced, and the layout is optimized as well. This process helps to reduce some repair waste such as waiting, inventory, traveling. On the top of that the lead time was reduced by 35% per set with repair hours saving by 15K yearly or USD 0.3M. Hence, PT XYZ are confident to accept the additional volume 13K from China.

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