Project Dissertation Report on

Process Improvements in Aerospace Manufacturing Industry using Value Stream Mapping & Process Certification

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CERTIFICATE

This is to certify that Deepak Garoo, Roll No: 2K19/EMBA/515 student of Master of Business Administration (Executive 2019-2021) at Delhi Technological University, Delhi has accomplished the project titled “Process Improvements in Aerospace Manufacturing Industry using Value Stream Mapping & Process Certification” under my guidance and to the best of my knowledge completed the project successfully, for the partial fulfilment of the course- dissertation in 4th semester of the course Executive MBA.

(Mr. Yashdeep Singh)
(Assistant Professor- DSM)

DECLARATION

I hereby declare that the submission is my own and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma from a university or other institute of higher except where due acknowledgement has been made in the text.

It is also urged that no piece of this project be re-produced in any form without the written consent of presenter.

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(**Deepak Garoo**)
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ACKNOWLEDGEMENT

I, Deepak Garoo, would like to place on record my deep sense of gratitude to Mr Yashdeep Singh for his support, guidance and mentoring for accomplishing this task.

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EXECUTIVE SUMMARY

The aerospace and defense industry is a major source of innovation and technological advancements. It plays a critical role in national defense, enables safe and efficient air travel, increases communication and the dissemination of knowledge, and contributes to increased consumerism and the globalization of supply chains.

Aerospace Manufacturers face several manufacturing process challenges, like any other manufacturing or process Industry. Order and delivery cycles for transport aircraft since 1958 are fairly regular, between 10 and 12 years long, but are always out of phase. During periods when the airline industry reaps profits, orders for new transport aircraft are placed. However, due to the length of time required for manufacturing, by the time the planes are ready, the airline companies are often facing a low market and therefore withdraw their orders. The ability of aerospace manufacturers to shorten the manufacturing and design build time is a critical challenge. Manufacturing optimization goals often include an evaluation of the existing process for its value add components and process capability to ensure predictable output.

Value stream (VSM) and process certification strategies are extensively utilized in aerospace manufacturing industry to enhance the effectiveness and capability of the manufacturing processes.

Value Steam Mapping is a special type of process flow chart that uses symbols as "the language of Lean" to depict and improve the flow of inventory and information. VSM provides optimum value to the customer through a complete value creation process with minimum waste in:

- Design (concept to customer)
- Build (order to delivery)
- Sustain (in-use through life cycle to service)

Value stream mapping is a tool that allows to see waste, and plan to eliminate it. It is different than the localized process improvements in that it ties the process elements together from end to end (cradle to grave) and determines how the value is delivered to customers with the identification of waste or liabilities within the process elements. Liabilities are those activities which are non-value added activities for which the customer doesn't pay for.

"VALUE" is defined as a capability provided to a customer and as what the customer is buying and as defined by customer.

- of the highest quality
- at the right time
- at an appropriate price

Applications of VSM are also presented by a practical implementation on an assembly process and reduction in Lead time, cycle time, processing time, and work in process inventory and manpower requirement at individual stations in an assembly process of any business process.

Variation, the law of nature, while it is true, is bad for Quality. It affects equally both manufacturing and administrative processes. In a manufacturing set up variation would mean unpredictable processes leading to waste generation and hence it is treated as an enemy.

Variation in a process is defined as a change or slight difference in condition, amount, or level, typically within certain limits. The variation in the quality of product in any manufacturing process are due to two reasons, Chance causes and Assignable causes. A process with only chance causes is said to be in a state of statistical control. This means, chance causes results in only minor variation in the process whereas assignable causes results in major variation in a process. Therefore, the main aim of process certification activity is to identify and rectify the assignable causes as soon as possible for an acceptable quality and control the effects of chance causes to a bear minimum.

Process Certification is the process variability reduction strategy utilized within Aerospace Manufacturing OEM's and their supplier bases. It is the application of statistical thinking to critical measures of a process's performance so that rational, data-driven decisions are made to improve and manage the process. It is a tool that helps to optimize the efficiency, effectiveness and quality of processes by reducing variation in products and services.

The objective of this project is to evaluate aerospace manufacturing process for effectiveness and process certification using various tools of VSM & Process certification, with following quantifiable measures.

- Reduction in Lead time
- Reduction in Cycle time
- Reduction in manpower Requirement
- Improvements in Process Capability

CONTENTS

INTRODUCTION

Aerospace Industry is truly Global Industry with greater symbolic power than any other Industry. It has sum of advanced technologies with high process complexities including supply Chain characterized by Low Volume, High Mix products. It is highly regulated industry. Requires long term employment focus with Management with Difference who are truly committed to Quality. Aerospace Industry is characterized by its documentation requirements as safety is paramount. Here, Inspection is not a non- value added activity but treated as a process. Paramount requirement for people within aerospace industry is their passion for the job with attitude for the reading and seeking answers and raising further questions.

Aerospace Manufacturing Industry in India is at its nascent stage with state owned company Hindustan Aeronautics Limited as the main driving force. With the liberalization of Indian economy and with Government intervention in setting up defense offsets policy. Indian Government has tried to utilize offsets to enhance domestic capabilities and these have become a recognized instrument by 130 countries. Many European nations have obtained 75 to 100 % offsets. Need for India to fully leverage offsets cannot be overstated. Indications are that military hardware requirement could be more than $ 200 billion till 2027. Offsets have taken time to get accepted in India, but offsets are now key in defense procurements. As a result for push for offsets, many International private companies that started Aerospace Sourcing from India. A good number of companies that entered aerospace market after introduction of Offsets and have acquired offsets work to grow in technology and products. Joint Ventures by foreign OEMs is another success of Offsets.

Long term focus as a pre requisite to be successful into Aerospace Manufacturing is hindered by challenges such as lack of Adequate Resources and Capabilities such as

- Non- Availability of Capital at competitive rates
- Non- Availability of Production Raw material in country. India is still importing most of the aerospace production raw materials from USA, Russia, EU
- Non- Availability of Manufacturing Eco-systems such as approved, qualified raw material test laboratories, Special process houses, NDT test houses
- Longer lead times and Inventory cycle times
- High Mix, Low Volumes of Products
- High Product Documentation requirements, sometimes the weight of the documentation can be more than weight of the parts.
- Longer Customer and Regulatory bodies (FAA) Federal Aviation Administration supplier approvals
- Non- Availability of skilled, certified manpower to stringent international standards, such as NDT personnel Qualifications to NAS-410 standard
- High warranty and product financial liabilities
- Stringent Quality Requirements on Product, Process and Systems
- 100 % Parts, 100% features Inspection is a requirement. Inspection is considered a value adding process in Aerospace Industry.

With all the above challenges, the objectives of ensuring both top and bottom line for a business entity becomes a distant dream. Process wastages and in-efficiencies are strict no-no. Besides having right strategy at the top, a clear focus on process optimization and efficiency will help to improve the processes. Techniques such as VSM & Process Certification are used to evaluate the current state of the processes and draw the desired state with capability improvements.

This mini project is an effort to study Value Stream Mapping technique and to evaluate process capability in terms of variability reduction and getting the processes under control and capable. It addresses some of the business challenges of Process optimization in terms of lead time reduction, cycle time reduction and reduction in manpower, and capability improvement at an Aerospace Manufacturer of aerospace engine parts.

Value Stream Mapping is a lean manufacturing planning tool to optimize results of eliminating waste. Value stream mapping involves following production path from the customer to a supplier and carefully drawing a visual representation of every sub process with the information and material flow. The asking of a set of questions and drawing a "future map", of how value should flow. Value stream mapping is an important tool as it helps us in

- Not only visualizing just the single process value, fabrication, assembly in production, but to see the entire flow.
- Mapping helps us to see the sources of waste than to see the waste itself.
- Provides a common language of talking about a manufacturing or a business process
- It makes decisions about flow apparent
- It utilizes the lean concepts
- It clearly shows the linkages between information and material flows.

Material and information flows are the two sides of the same coin. Within a production flow, the movement of material flow through a factory is accompanied by another flow, the information flow, which tells each process what, how much to produce and when to produce. Material and information flow generally happen in reverse direction to each other.

A very important part of the value stream mapping process is documenting the relationships between the manufacturing processes and the controls used to manage these processes, such as production scheduling and production information. Unlike most process mapping techniques that often, only document the basic product flow, value stream mapping also documents the flow of information within the system, where the materials are stored (raw materials and work in process, WIP) and what triggers the movement of material from one process to the next are key pieces of information.

Value Stream Mapping (VSM) is used to define and analyze the current state for a product value stream and design a future state focused on reducing waste, improving lead-time, and improving workflow. A value stream map provides a blueprint for implementing lean manufacturing concepts by illustrating how the flow of information and materials should operate. VSM is divided into two components: current state and future state by layout modification or other kaizen activities and balance to TAKT time Problems in existing process. TAKT time is the time required to get a part or an assembly as required at the demand rate of customer.

$$\textbf{Takt Time} = \frac{\textbf{Effective Working Time per Shift}}{\textbf{Customer Requirement per Shift}}$$

For example, if the takt time is 2 minutes, it means every two minutes a part, assembly or a machine is produced off the line. Takt time is also known as “beat rate” of the process.

VSM Methodology

VSM implementation is a cyclic process with elements broken down into steps

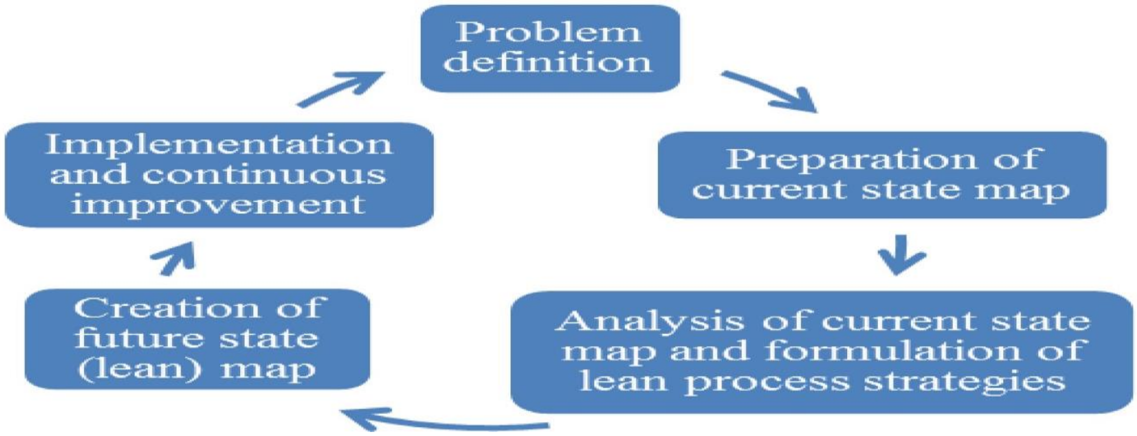
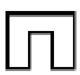


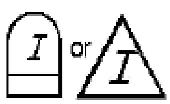
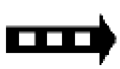
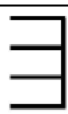
Fig 1

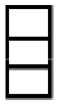
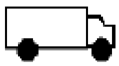
- Step 1: Select your sponsor or set our expectations. Appoint someone who is responsible to make decisions, arbitrate solutions, and plan the VSM event. Sponsor usually selects the process that will be mapped and will have firm grasp of what achievement is being targeted.
- Step 2: Select your team. Team needs to be cross functional and must represent each of the areas, you wish to improve.
- Step 3 : Select the process to be mapped. The process could be any business or a manufacturing process.
- Step 4 : Collect data and produce current map. Data related to Process times, inventory, and customer demand, wait times etc, need be collected. The current state map will be created using information captured here, so it is imperative that you have correct process information.
- Step 5: Critique current state. Challenge the current thinking. Encourage the team to critically examine the process steps and identify opportunities for improvements with the objective of meeting customer Takt time requirements and elimination of wastage from the process.
- Step 6: Map future state. Compile a future state map based on the current state map and the critique in step 5 above.
- Step 7 : Create an action plan and deploy. An action plan needs to be developed the change from current state to future state.

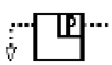
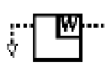
- Step 8: Measure benefits. Check to ensure expected benefits have been obtained with a review of each change made and analyzing benefits.

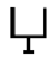
Value Stream Process Mapping Symbols

	Customer/Supplier Icon: represents the Supplier when in the upper left, customer when in the upper right, the usual end point for material
	Dedicated Process flow Icon: a process, operation, machine or department, through which material flows. It represents one department with a continuous, internal fixed flow.
	Shared Process Icon: a process, operation, department or workcenter that other value stream families share.
	Data Box Icon: it goes under other icons that have significant information/data required for analyzing and observing the system.
	Workcell Icon: indicates that multiple processes are integrated in a manufacturing workcell.

	Inventory Icons: show inventory between two processes
	Shipments Icon: represents movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customers
	Push Arrow Icon: represents the "pushing" of material from one process to the next process.
	Supermarket Icon: an inventory "supermarket" (kanban stockpoint).
	Material Pull Icon: supermarkets connect to downstream processes with this "Pull" icon that indicates physical removal.

	FIFO Lane Icon: First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input.
	Safety Stock Icon: represents an inventory “hedge” (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures.
	External Shipment Icon: shipments from suppliers or to customers using external transport

	Production Control Icon: This box represents a central production scheduling or control department, person or operation.
	Manual Info Icon : A straight, thin arrow shows general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant.
	Electronic Info Icon : This wiggle arrow represents electronic flow such as electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network). You may indicate the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged.
	Production Kanban Icon : This icon triggers production of a pre-defined number of parts. It signals a supplying process to provide parts to a downstream process.
	Withdrawal Kanban Icon : This icon represents a card or device that instructs a material handler to transfer parts from a supermarket to the receiving process. The material handler (or operator) goes to the supermarket and withdraws the necessary items.

	Signal Kanban Icon : used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. It is also referred as “one-per-batch” kanban.
	Kanban Post Icon : a location where kanban signals reside for pickup. Often used with two-card systems to exchange withdrawal and production kanban.
	Sequenced Pull Icon: represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket.
	Load Leveling Icon : a tool to batch kanbans in order to level the production volume and mix over a period of time.
	MRP/ERP Icon : scheduling using MRP/ERP or other centralized systems.

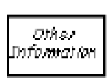
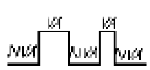
	Kaizen Burst Icon: used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.
	Operator Icon : represents an operator. It shows the number of operators required to process the VSM family at a particular workstation.
	Other Icon : other useful or potentially useful information.
	Timeline Icon : shows value added times (Cycle Times) and non-value added (wait) times. Use this to calculate Lead Time and Total Cycle Time.

Fig 2

Process Certification on the other hand is a six step strategy to improve processes, which makes use of data, for decision-making. A manufacturing process becomes a candidate for certification when it is capable, under statistical control (stable and predictable), and is complemented by an approved control plan. The focus of Process Certification is to reduce manufacturing process variations by controlling inputs and outputs.

Process Certification is accomplished using a six step process. The steps are:

The tool can be though off as having a strong relationship with other quality tools like 8D,6-Sigma,PDCA etc

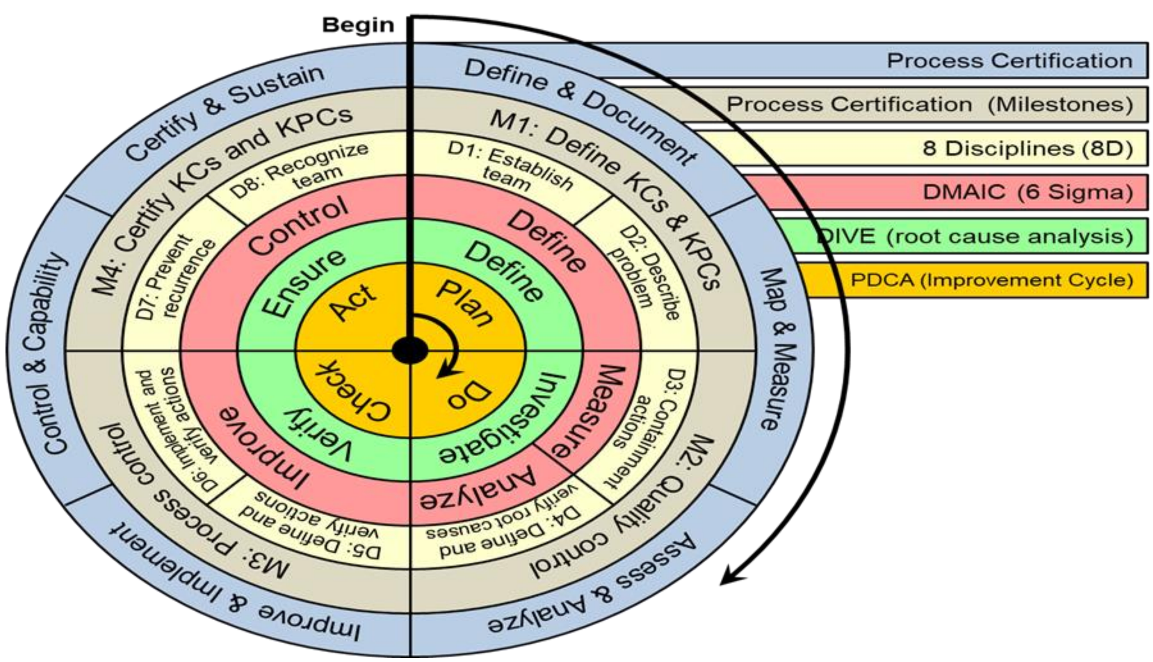


FIG : 3 – Process Certification V/S other Improvement Tools

This tool is used to:

- Minimize and eliminate product or service variation
- Control a process to produce more predictable results
- Improve product and service quality customer satisfaction

Stag 1: Define and Document

Process Certification is best embarked upon using the team approach. Conceptually, this is a culture change requiring a proactive approach instead of the more familiar reactive approach. Team member involvement creates "buy-in" and offers a valuable opportunity for a wider spread of the Process Certification notions. A team effort is usually more effective than an individual effort. Define and document stage starts with the identification of Parts/ Processes for certification, identifying design related risks via Design Failure mode & effect analysis (DFMEA) and finally identify key product/Process KC's. KC's are key product or process features whose variation, if not controlled can result into quality issues affecting either safety, performance or fit or function of the part or assembly.

Milestone 1 is achieved at the end of Process Certification stage 1. The milestone is reached with the

- Identification of material and part features and process parameters that are to be certified is complete. These are the Key Characteristics (KCs) and which must be certified in later stages of the process certification
- Confirmation of KCs with internal and external stakeholders and flow down to them
- Conducting Design risk analysis on each design functionality that creates identified KCs, in terms of design failure effects in terms of their severity,

causes of potential failures and possible prevention and detection controls in design step

Stag 2: Map & Measure

The purpose of this stage is to gather knowledge and facts to

- Better understand the steps of the process
- Identify and establish a plan to reduce risk of a failure
- Identify process KCs to be managed with a control plan
- Assure capable measurement systems

The stage begins with the creation of a process map and carrying out process failure mode effect analysis (PFMEA), identifying Process Key characteristics affecting fit, function, safety or performance of the component and performing appropriate measurement system analysis (MSA).

Stage 3: Assess & Analyze

Purpose of this stage is to assess and analyze the process stability and capability of current state of the processes which create the KCs being certified. Steps involved in this stage are:

- Appropriate process data is collected, which could be either variable or attribute.
- Process stability is assessed, using trend charts and control charts to look for evidence of (or lack thereof) of any special cause patterns in the data.
- A first look at a process capability is performed using appropriate capability metrics (Cp, Cpk, Pp, and/or Ppk)

Milestone 2 is achieved at the end of Process Certification stage 3. The milestone is reached with the

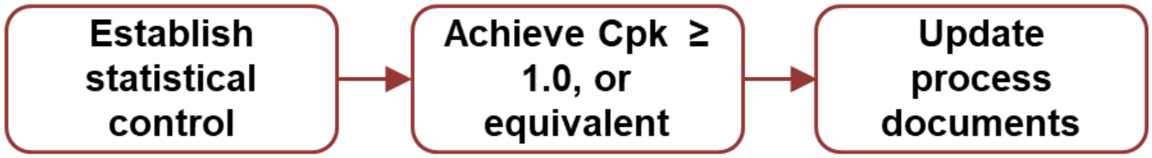
- Documentation of a detailed process map for the process
- Perform process FMEAs and set up the control plan for the KCs
- Performing the appropriate measurement system analysis (MSA) studies for each KC
- Conducting a preliminary process capability study for each identified KC

Stage 4: Assess & Analyze

The Purpose of this stage is to Identify and implement the necessary actions to address processes found to be lacking statistical control and/or capability as identified in stage 3. An action plan of various process improvements is prepared, implementation is ensured and verification of the results of process improvement activities is carried out.

Stage 5: Control & Capability

The purpose of this stage is to establish the required process controls and work instructions such that the Key Characteristic being monitored is predictable and capable of meeting the voice of the customer. A process that is in statistical control as illustrated through the use of a control chart. Control Chart technique is the use of process data to identify special causes of variations in the process and data can be plotted in a time sequence.



Process is considered to be in control if

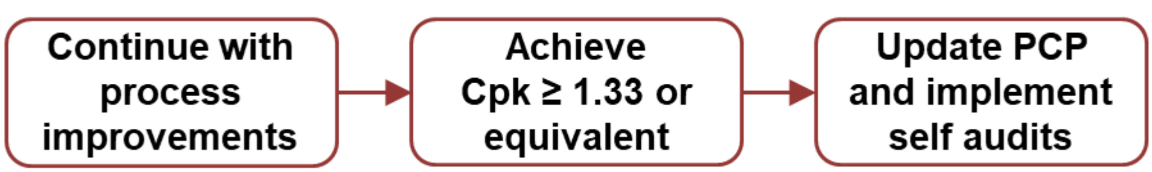
- All special causes have been removed and process is running under the influence of common cause variation only
- A Process Capability Index Cpk equal or greater than to 1.0.
- A documented Process Control Plan is in place that documents the process steps KPIs, KPOs, key characteristics, control methods, measurement systems and reaction plans

Milestone 3 is achieved at the end of Process Certification stage 5. The milestone is reached with the

- Control Chart established with at least 25 data points collected over time
- Control Chart illustrates statistical control
- Process Capability Cpk equals at least 1.0
- A Process Control Plan is documented illustrating process control strategy to reduce PFMEA high risks identified and Key Characteristic control

Stage 6: Certify & Sustain

The purpose of this stage is to achieve a certified process and ensure it stays that way. The stage begins with continued process improvements to achieve Cpk ≥ 1.33 followed up with updation of process control plan.



Process certification is achieved when

- Statistical control achieved for each KC.
- Cpk ≥ 1.33 or equivalent for each KC.
- Continued monitoring of the process using control charts or pre-control charts.
- Control Plan in place & Self audit process is in place

Milestone 4 is achieved at the end of Process Certification stage 6. The milestone is reached with the

- Put in place ongoing monitoring of process stability and capability
- Reduce common cause variation to a point where process capability has reached Cpk ≥ 1.33
- Put in place ongoing process certification System audits

CASE STUDY

A case study was conducted at an Aerospace manufacturing organization within India. The organization is a sub tier to one of the global aerospace engine OEM. The production line was properly examined and a major product contributing to highest non-value added time was selected for the case study. All the primary and secondary data was collected for further study. Both, value added and non-value added time along with the lead time of the product was calculated. The Bottleneck operations were identified. It is a small manufacturing industry and manufactures the various components used for aerospace commercial engines and in present case, Bleed Valve manufacturing line was selected for study.

For manufacturing Bleed Valve, the company has a long term price negotiated contract with its customer located in USA. Periodic Purchase orders are flowed down to the organization electronically for fixed quantities. Part Procurement and requirement scheduling happens electronically through EDI process with one month of firm schedules and twelve months of floating schedules. Organization utilizes these schedules to plan its raw material requirements and flows down orders to raw material sources. Raw material sources are located in USA and are qualified by the OEM. Organization has to import raw material directly from these OEM approved mills/ Distributors in USA and manufacture the part using standard five axis CNC machining centers. It utilizes the services of an outside vendor for Non-Destructive test and for special coating prior to final inspection. The part has to be moved to customer over-inspection area for ensuring compliance to customer purchasing requirements, prior to packaging and delivery to customer. Customer Incoterms for this part are Ex-works and it takes five days to dock the material into customer stated warehouse.

CURRENT STATE MAP

Current state map is prepared keeping in view the existing manufacturing and support business processes from customer to supplier value chain. All the data required for this map is taken from the shop floor of the selected part followed by discussion with workers, supervisors and managers of the organization.

Current maximum monthly demand for the Part is 3500 Pcs and the company operates on a three shift basis with productive available time available per shift as 7 hrs for first two shifts and 6 hrs for third shift. The current state map captures information for each of the process steps. Effective numbers of working days are 20 per month.

Available working time per month is 24,000 minutes

Takt time can be calculated Takt time= {(Available working time per day (minutes)/customer demand per day (units)}={(1200/(3500/20)}=6.86 minutes.

Current state map is shown in Fig. 3. The daily demand from the customer is indicated through pick list in the EDI platform and the organization has to meet the daily pick requirements of the customer. Production Planning is decoupled from the pick list and works on the firm monthly requirements indicated by the customer. Planning department loads the manufacturing router in the shop floor which starts with raw material cutting and issuance. Raw material suppliers work on the rolling plan indicated by the organization based on customer forecasts, because of large raw material lead times. Organization keeps raw material inventory of six months in their raw material store. Material moves from raw material store to finished goods store through a number of processes/machines raw material cutting and issue, CNC 5- axis turning, hexagonal punching, CNC Milling, Centre less grinding, de-burring, Part marking, NDT Testing, Special Coating, Final Inspection, Over Inspection, Packaging/ Labelling and Dispatch. Details regarding inventory, cycle time, lead time, are shown in Fig. 3 against every operation. As required by customer Organization carries finish goods inventory of one and a half months.

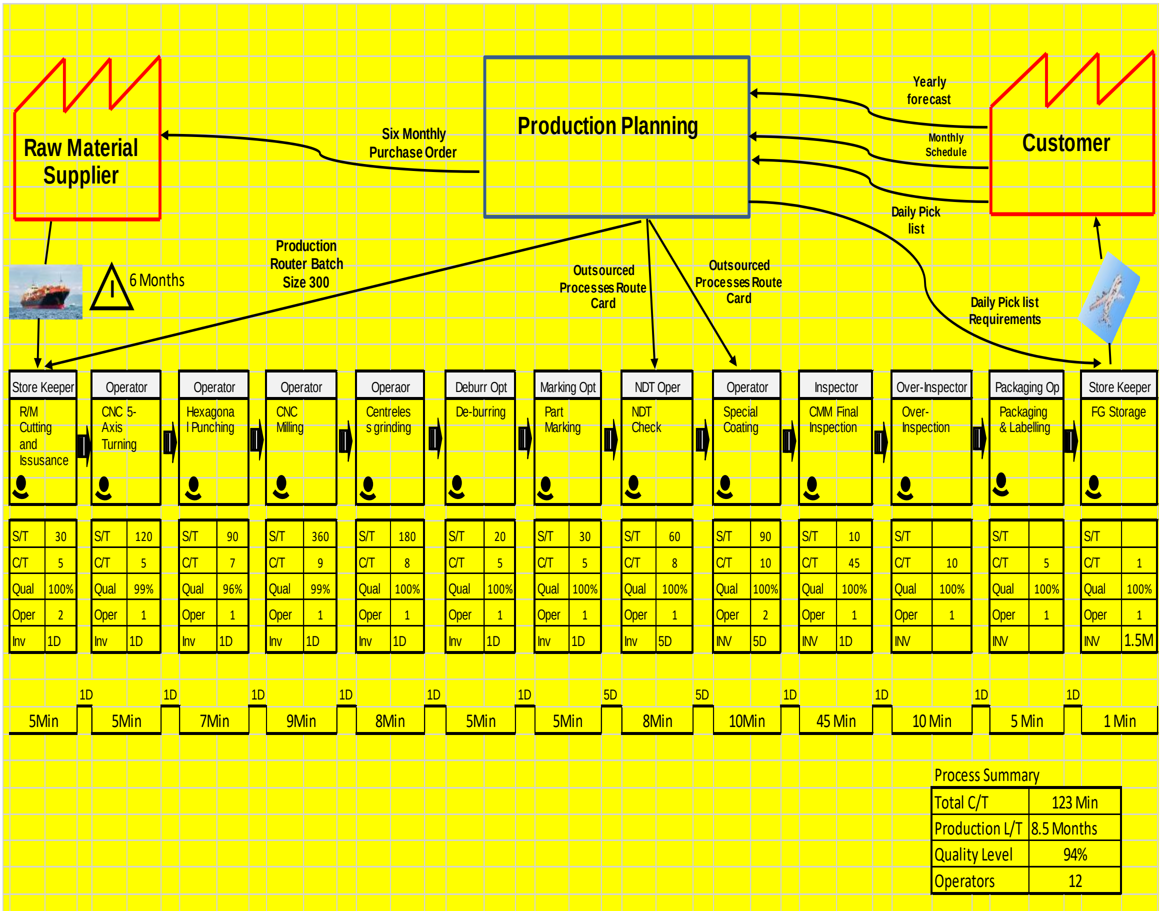


FIG : 3 – Current State Process Map

Chart 1, shows the work balance chart, a comparison of Takt time with individual process cycle times & it is seen that following process cycle times are above the customer required Takt time rate of 6.8 minutes

- Final Inspection Process
- Over Inspection Process
- Special Coating Process
- NDT check Process
- CNC Milling Process &
- Centreless grinding Process

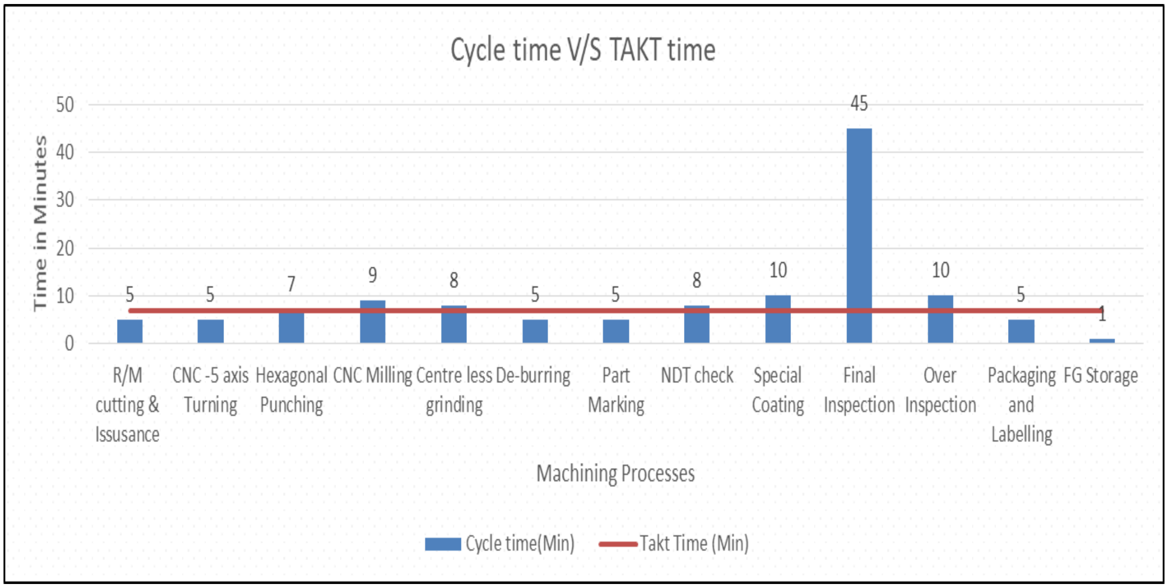


Chart 1 – Work Balance Chart of Current State

In Summary, the actual processing time or the real value-adding time for the existing process is 123 Minutes, whereas lead time is 8.5 Months. Maximum work in-process inventory of 1.5 Months of Bleed Valves are there at factory end. Total manpower required in existing state of Bleed Valve manufacturing line is 12 persons/operators. Overall Quality level of the process is 94%, which is arrived by multiplying individual quality level at each process step.

Some of the problems that can be seen with the current value stream are:

- High Process lead time, which can be ascribed to import of aerospace raw materials and the scarcity of raw material at the mills. Raw Material distributors are channel partners of raw material mills and have greater flexibility in terms of their locating the warehouses. Certification requirements of a new warehouse by OEM's are relatively low than that of the mill and could be influenced to locate their warehouse in country. This would be possible with the consolidation of raw materials from various manufacturers that would help them to set up their warehouses within country.

- High level of required inventory of finished goods by organization. This is a stated need of customer and is agreed upon by the organization. Hence, not much can be done in this area.

- Some of the process cycle times are relatively higher than the value Takt time requirements and could be prioritized for process improvements

- NDT Checking and Special Coating processes are currently outsourced to a customer approved source and involve to & fro transportation. Special Process houses are the weakest link in the supply chain and thus the cause of high parts inventory at these locations.

- Process Capability Cpk index for Mill turn center for DIA : Ø6.615 ± 0.015 mm is less than 1.0, requiring 100% inspections as per customer requirements. Process Capability is calculated after ensuring process is stable by eliminating all special causes of variation using X-Bar, R-Chart. Reference Fig 4 below.

- Cpku = 0.654 , Cpkl = 0.589 (Cpk = 0.589)

	USL	6.630		LSL	6.600																				
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	6.612	6.613	6.606	6.604	6.603	6.603	6.608	6.625	6.618	6.625	6.607	6.607	6.608	6.607	6.608	6.607	6.629	6.605	6.607	6.623	6.613	6.618	6.614	6.627	6.607
2	6.623	6.606	6.618	6.625	6.626	6.615	6.609	6.622	6.627	6.612	6.607	6.615	6.612	6.613	6.612	6.626	6.628	6.602	6.623	6.612	6.602	6.619	6.615	6.622	6.612
3	6.605	6.615	6.615	6.620	6.615	6.623	6.615	6.607	6.615	6.615	6.621	6.609	6.615	6.625	6.603	6.615	6.615	6.603	6.625	6.605	6.605	6.615	6.607	6.625	6.611
4	6.625	6.624	6.620	6.625	6.625	6.625	6.612	6.609	6.603	6.610	6.608	6.610	6.610	6.626	6.622	6.626	6.602	6.610	6.609	6.611	6.621	6.608	6.608	6.610	6.618
5	6.608	6.609	6.629	6.608	6.602	6.605	6.604	6.607	6.608	6.625	6.624	6.607	6.624	6.607	6.623	6.605	6.621	6.611	6.607	6.607	6.627	6.623	6.628	6.606	6.624
X-Bar	6.615	6.613	6.618	6.616	6.614	6.614	6.610	6.614	6.614	6.617	6.613	6.610	6.614	6.616	6.614	6.616	6.619	6.606	6.614	6.612	6.614	6.617	6.614	6.618	6.614
Range	0.020	0.018	0.023	0.021	0.024	0.022	0.011	0.018	0.024	0.015	0.017	0.008	0.016	0.019	0.020	0.021	0.027	0.009	0.018	0.018	0.025	0.015	0.021	0.021	0.017
	X-2 Bar	6.614	UCLx	6.625	LCLx	6.603	Sigma			0.008		Cpku		0.654		Cpk		0.589							
	R-bar	0.019	UCLr	0.04	LCLr	0	Cp			0.621		Cpkl		0.589											

FIG : 4 – Process Capability Analysis

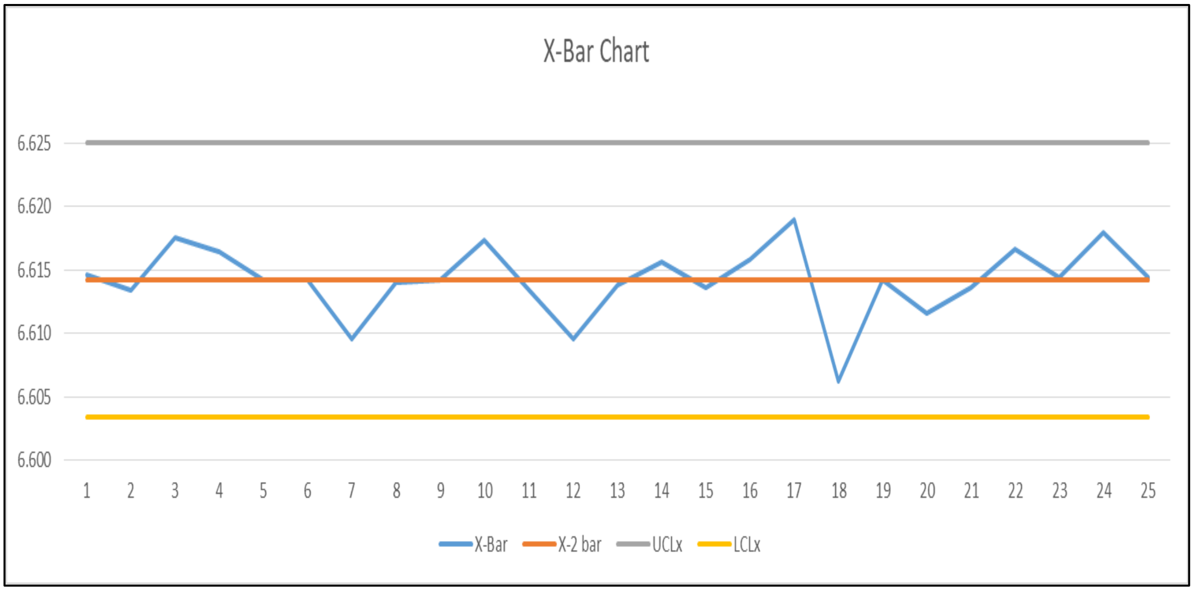


FIG : 5 X- Bar Chart

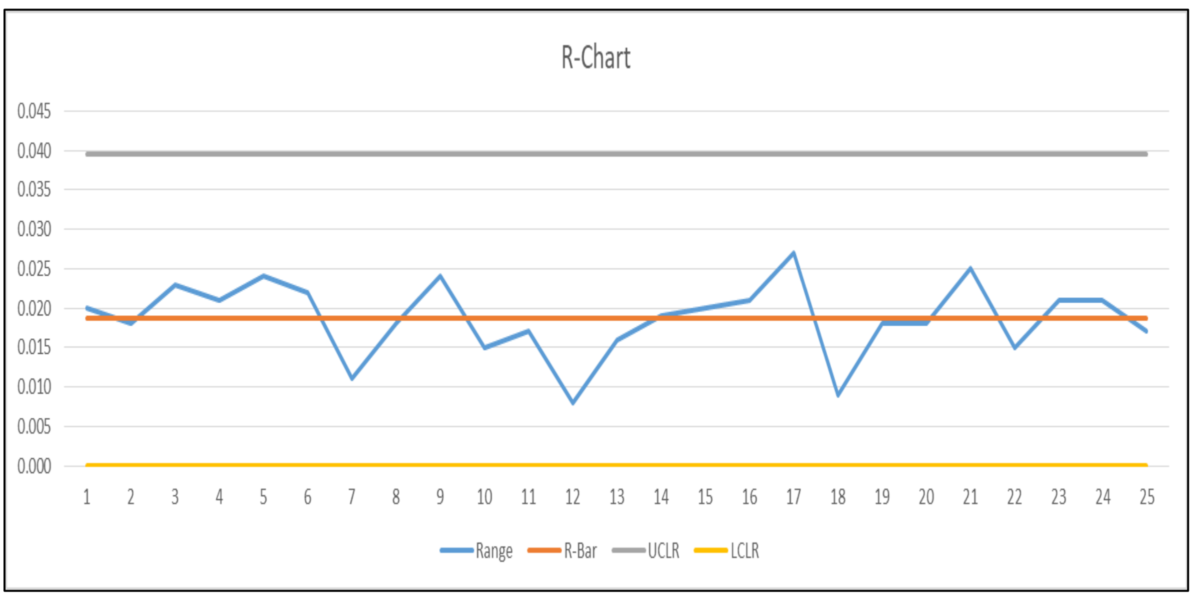


FIG : 6 – R-Bar Chart

FUTURE STATE MAP

Prior to attempting to draw future state process map, it is important to understand seven Manufacturing Process wastes:

- Transport
- Inventory
- Movement or Motion
- Waiting/Delay
- Over production
- Over processing
- Defects

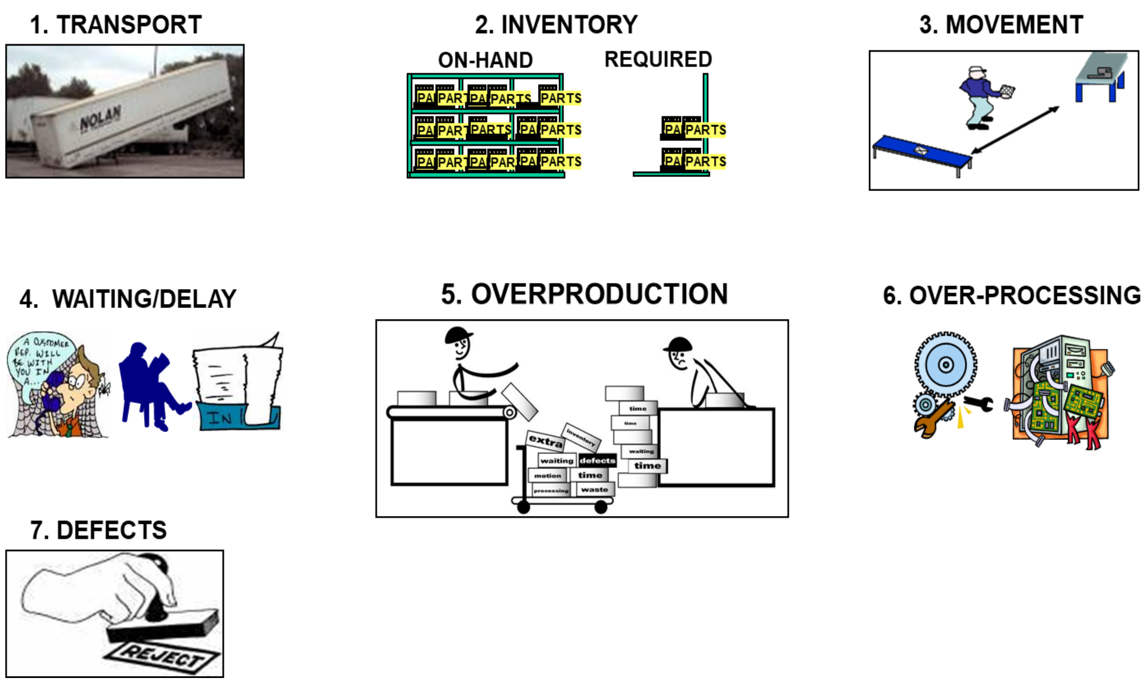


Fig 7

A future state vision can't be implemented all at once. VSM team is in charge of developing future state vision and breaking implementation into steps. Process Improvement plan or Kaizens are the next step to start implementing the Future State. Following Kaizens were initiated to improve the flow:

- Organization was successful in getting raw material distributor set up warehouse facility within India. Organization worked with distributor and supported them with their quality management systems to obtain necessary quality management system certifications AS9120 and necessary customer approvals. With the approvals in place, distributor was able to support the organization from its warehouse location within India with the facility only at a distance of 15Kms from the organization.

- With the above change, Purchase order flow down frequency was increased and instead of placing purchase orders once in six months, monthly purchase schedules were provided to warehouse.

- Stock of Inventory of raw material was as well reduced to 15 days at organization.

- Final Inspection was being carried out on CMM with a Process Cycle time of 45 minutes. This surely was a bottle neck process and improvements to reduce inspection time were thought off, without compromising on quality of inspections. Part positional gauges were designed, validated and with customer approval were used to inspect the parts. This speeded up entire final inspection process and freed CMM capacity to take on other developmental works.

- For the outsourced processes like NDT checks and Special coating processes, an alternate strategy of investing in building these capabilities in house and with necessary customer process approvals, these were seamlessly integrated into other organization in house manufacturing processes. This strategy not only helped to reduce the lead times but as well helped reduce transportation costs for the organization.

- Manufacturing process improvements and the tool adaptor design change in CNC milling process, which made possibility of clubbing hexagonal punching process with CNC milling. This helped to reduce process cycle times to 10 minutes in the combined process as compared to an aggregate of 16 minutes for two processes individually. The change also helped to save one skilled resource.

Above process adaptations were carried out as first step in future state mapping of the value change. As process kaizens are a continuous process, there is scope for further improvements. Fig 8, below shows the future state process map

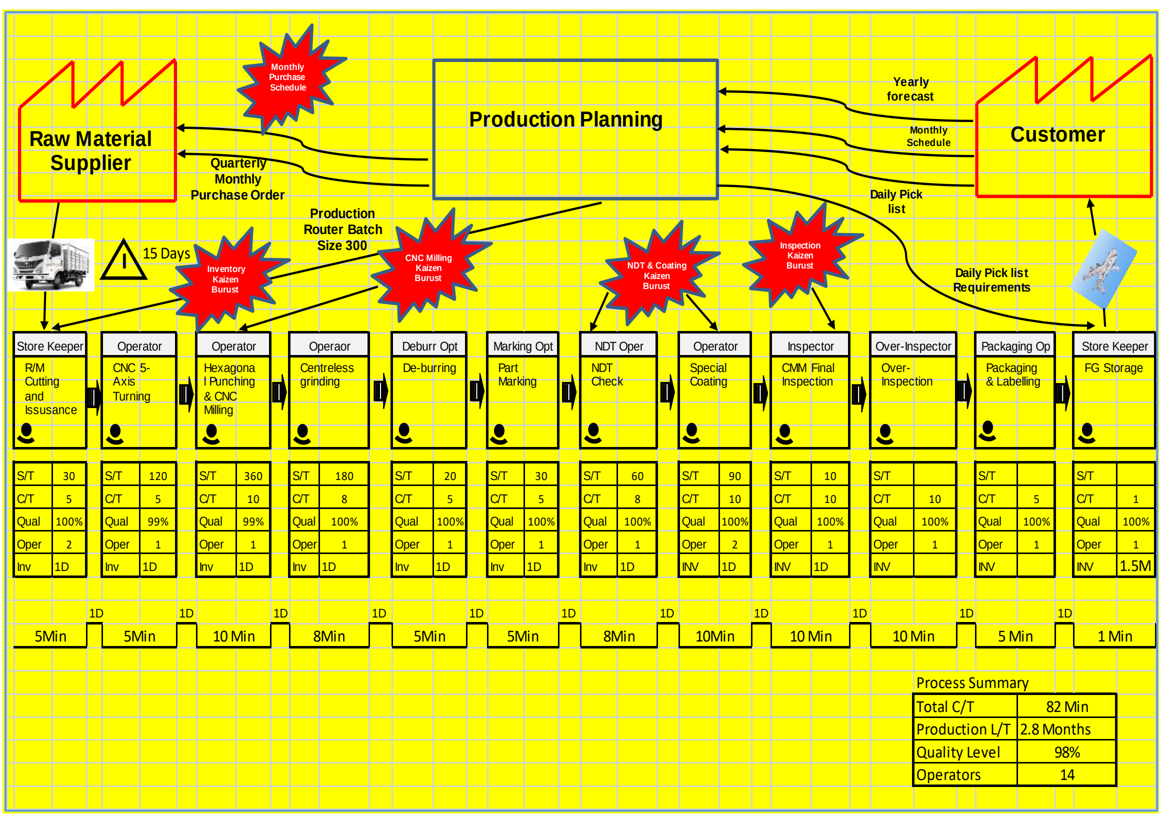


FIG : 8 – Future State Process Map

Chart 2, shows the work balance chart, a comparison of Takt time with individual process cycle times for future state map. There is still scope of improvement in the process Value Stream.

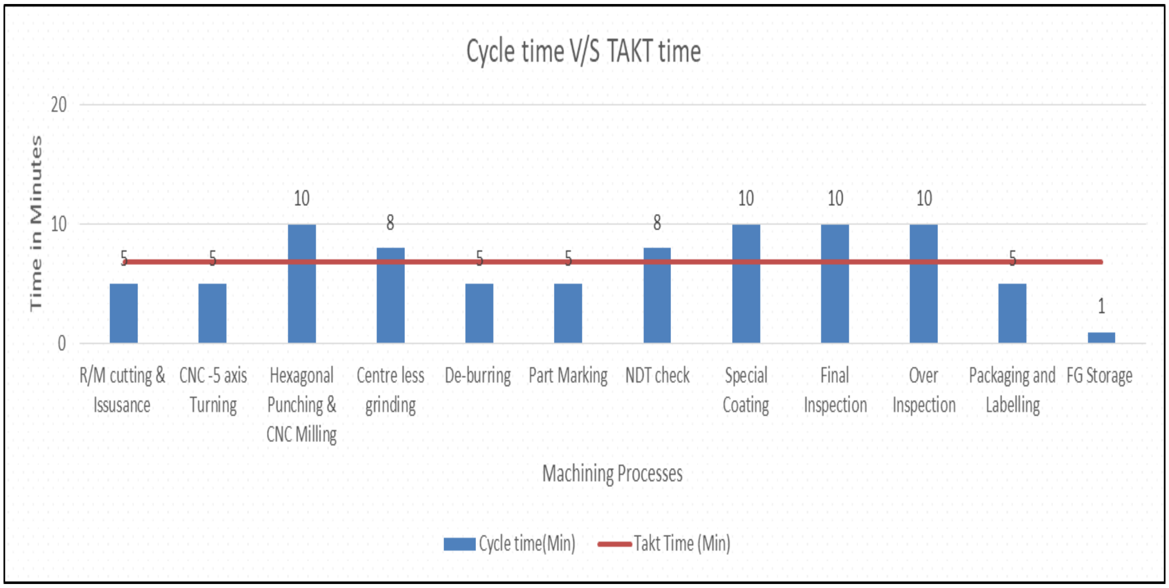


Chart 2 – Work Balance Chart of Future State

Using Process Certification tools like Process Flow diagram (Fig 10) , Process Risk Analysis, PFMEA (Fig 11) , all relevant inputs and outputs were analyzed at each step. Reasons for low process Capability were analyzed in cross function team using fish bone tool (Fig 9).

Fish Bone Analysis

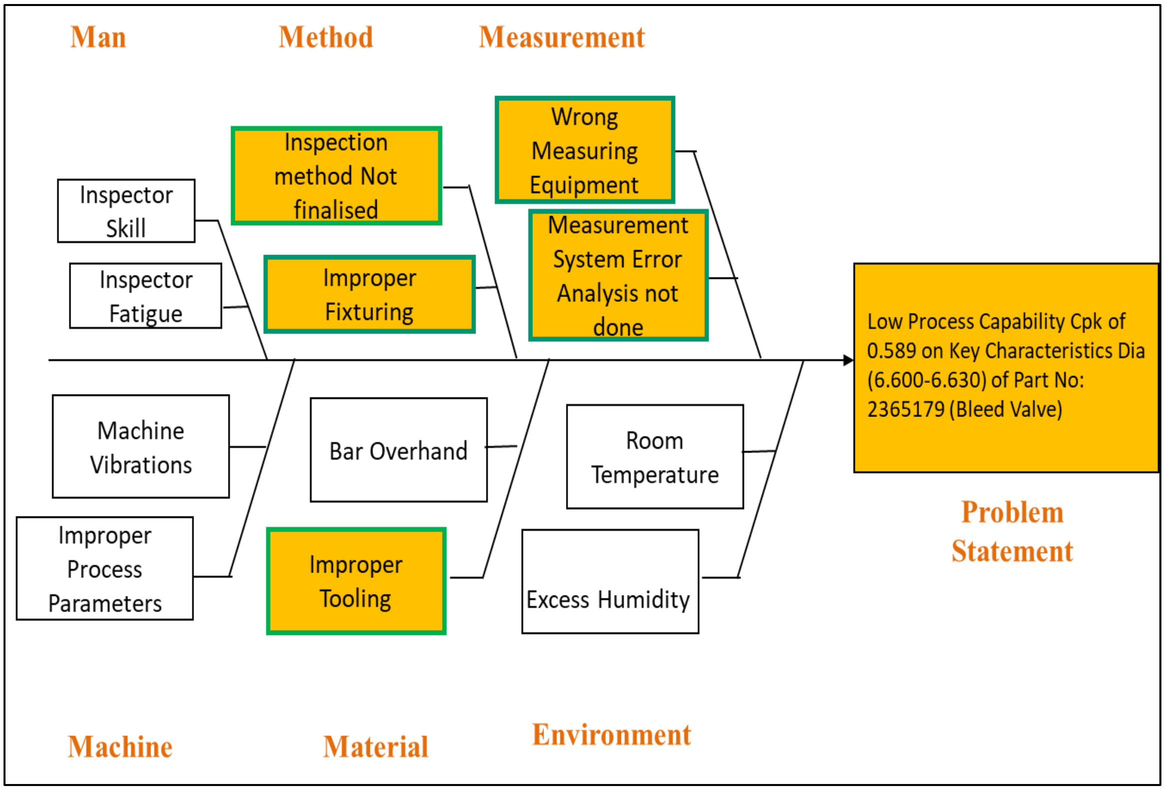


FIG : 9 – Fish Bone Diagram

Process Flow Diagram

PROCESS FLOW DIAGRAM

Part Name:	Bleed Valve	**Dwg Rev:**	A
Part #:	2365179	**Process Flow Rev:**	00
		Prepared by:	Deepak Garoo

Operation #	Process Step	Process Function/ Description	ADMINISTRATION ●	PACKAGING INTERACTION ■	LIFT (mechanical / other) ⇧	LOAD / INSTALL ⇩	FABRICATION / TRANSFORMATION STEP ◇	MOVE ○	STORE △	INSPECT □	REWORK ✖	OTHER (Specify)	Special Characteristic Classification	Key Process Outputs (KPO) (Product Characteristics) Requirments	Key Process Inputs (KPI) (Process Characteristic) Sources of Variation
005	Raw Material cutting $ Issusance	Issue the RM with identification of Part#, Work Order # and Serial # to production					◇							1. ISSUE OF IDENTIFIED FORGING TO PRODUCTION 2. IDENTIFY THE PART SERIAL NO, BATCH NO, HEAT NO AND WORK ORDER NO ON EACH BAR STOCK	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/005 REV 00 2. CONTROL PLAN: CP/5331038 REV 00
010	CNC 5-Axis turning	Clamp the Rawmaterial in Fixture & Ensure the RM Alignment, for Facing, OD machining, drilling & T-slotting					◇							OUTER DIAMETER : Ø7.7 ± 0.40 mm	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/010 REV 00 2. TOOL SETUP SHEET TSS/5331038/010 Rev 00 3. NC PROGRAM (O1000 - O1007)
015	Hexagonal Punching & CNC Milling	Reverse the part in Y-Direction at 180°, locate the part on fixture by using dowel holes for Facing, OD Profile machining,Punching					◇						KEY	DIA : Ø6.615 ± 0.015 mm	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/020 REV 00 2. TOOL SETUP SHEET TSS/5331038/020 Rev 00 3. NC PROGRAM (O2000 - O2013)
020	Centreless Gringing	OD grinding					◇							1. OUTER DIAMETER : Ø8.15±0.30 mm	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/030 REV 00 2. TOOL SETUP SHEET TSS/5331038/030 Rev 00 3. NC PROGRAM (O3000 - O3005)
030	Deburring	Remove Machining Burrs					◇							1. BREAK SHARP EDGES: 0.0762 - .0.381 mm	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331171/079 REV 00 2. SKILLED OPERATOR 3. CONTROLLED ENVIRONMENT WITH LIGHT CONTROL LUX1000
035	Indentification Marking Machine: Manual Engraving	Manual Engraving as per Customer Approval					◇							TO MARK PART NUMBER & SL NO	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/110 REV 00 2. CUSTOMER APPROVED MARKING CONTENT 3. MARKING TEMPLATES & SKILLED OPERATOR
040	NDT - FPI	Carry out Fluorescent penetrant Inspection					◇							FPI INSPECTION REPORT # 51-69-56 REV 02	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/120 REV 00 2. NDT AS PER AOP-NDTFPI-02
045	Special Coating	Sulphuric acid Anodization as per AMS 2470					◇							1. TO CHECK THE COATING THICKNESS, CONTINUITY CHECK 2. VISUAL INSPECTION	1. MANUFACTURING OPERATION SHEET - PROCESS INSTRUCTION : OSN/5331038/140 REV 00 2. SULFURIC ACID ANODIZING AMS 2470 AS PER CONTROL PLAN NO: U5ST011002010 3. CUSTOMER APPROVED SOURCE
050	CMM Final Inspection	100% Parts Inspection								□				1. ENSURE ALL BLUE PRINT REQUIREMENTS ARE MET 2. CMM INSPECTION REPORTS 3. FINAL INSPECTION REPORT 51-27	1. CUSTOMER APPROVED INSPECTION METHOD SHEET (IMS) # 51-24 2. CUSTOMER APPROVED CMM PROGRAMS 3. CMM INSPECTION FIXTURE # J501100002Q18C00101 REV 00
055	Over Inspection	100% Visual & Final Inspection for Parts								□				1. ENSURE ALL BLUE PRINT REQUIREMENTS ARE MET 2. FINAL INSPECTION REPORT # 51-27 REV 00 3. NO NICKS, SCRATCHES, DENTS , VISUAL INDICATIONS etc	1. CUSTOMER APPROVED INSPECTION METHOD SHEET 2. INSPECTION GAUGES PER IMS 3. CONTROLLED COPY BALLOON DRAWING, CMM REPORTS, LAYOUT INSPECTION REPORTS 4. CONTROLLED ENVIRONMENT, LIGHTING TO BE 1000LUX
060	Preservation and Packaging credit to FG stock	Preserve and pack the part at stores as per Packaging Procedure		■										1. APPROPRIATELY PACKAGED FINISHED PART WITH ACCEPTED TAG: T/51/69/01 REV 00	1. MANUFACTURING OPERATION SHEET- PROCESS INSTRUCTION : OSN/5331038/250 REV 00 2. PRESERVATION PROCEDURE # AOP-PCK-12

FIG : 10 – Process Flow Diagram

Process Failure Mode Effect Analysis

Process Failure Mode and Effects Analysis (PFMEA)

PART No.	2365179
REV.	
PART NAME	Bleed Valve

PFMEA Team:	Deepak, Jai Kishore, Karan
Prepared By:	G.JOHN
Date: (Original)	3/17/2021
(Revised)	00

Operation Sequence	Process Description	Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Current Process Controls (Prevention)	Current Process Controls (Detection)	Detection	RPN	SD	SO	Recommended Action	Severity	Occurrence	Detection	RPN	SD	SO	RPN
015	Hexagonal Punching & CNC Milling	OD within Specification	Under size	100% of product may have to be scrapped. Line shutdown or stop ship.	6	Tool wear	3	Tool life monitoring Sheet & Tool Data sheet	Setup Approval & Inprocess Inspection	7	126	42	18	Tool life will be stabilized in 1st production batch.							
					6	Wrong Inspection method / Instrument.	2	Inspection methods defined thru Control Plan : IMA -QA-FF-18		7	84	42	12	MSA to be carried out and use X-Bar Chart for statistical control and Capability							
					6	Non calibrated gauges	2	Calibration Recall notice (IMA-QA-FF-51)	Provide Sticker on gauges after review of Calibration report & gauge history card	5	60	30	12	None							
			Over size	100% of production run may have to be reworked off line and accepted.	6	Tool wear	2	Tool life monitoring Sheet	Setup Approval & Inprocess Inspection	7	84	42	12	None							
					6	Wrong Inspection method / Instrument.	2	Control Plan : IMA -QA-FF-18		7	84	42	12	None							
					6	Non calibrated gauges	2	Calibration Recall notice (IMA-QA-FF-51)	Provide Sticker on gauges after review of Calibration report & gauge history card	5	60	30	12	None							

FIG : 11 – Process Flow and Effect Analysis

After Process flow diagraming, Risk Analysis (PFMEA) and Fish bone Analysis , following improvement initiatives were taken to improve the capability of the process.

- Carbide tooling was introduced instead of HSS
- More rigid tool holder was used
- Part holding fixture with pneumatic clamps was introduced
- Feed and speed was reduced to reduce the backlash
- Measurement system was improved from Vernier caliper to Micrometer of LC=0.001 mm.
- Measurement study analysis MSA (GRR) was carried out for Micrometer (Fig 12)

MEASUREMENT VARIABILITY WORKSHEET

PAGE #1

GAUGE	Micrometer (0-10mm)	PART NO	2365179
CALIBRATION DATE	2/Jul/21	PART NAME	Bleed Valve
CALIBRATED BY	Balamurugan.S	CHARACTERISTIC	Outer diameter
GAUGE NO	8603051	SPECIFICATION	ø6.600~6.630
CODING ZERO	-	GRADUATION	0.001mm
UNIT OF MEASURE 1=	1.	EVAL'S NAME	Deepak
TOLERANCE	0.03 ===> (0.0300)	DATE	24-Mar-21

DEPARTMENT : Machined Parts ☑ Sheet Metal ☐ Heat Treatment ☐ Assembly & Test ☐ Dept.: PEC-QC

OPER	A: Deepak				B: Raj				C: Jai Kumar			
Sample number	REPLICATIONS				REPLICATIONS				REPLICATIONS			
	1	2	3	R	1	2	3	R	1	2	3	R
1	6.617	6.618	6.617	0.00100	6.618	6.619	6.618	0.00100	6.616	6.615	6.617	0.00200
2	6.620	6.621	6.622	0.00200	6.617	6.615	6.615	0.00200	6.622	6.621	6.621	0.00100
3	6.618	6.617	6.618	0.00100	6.620	6.621	6.621	0.00100	6.617	6.618	6.615	0.00300
4	6.622	6.620	6.621	0.00200	6.621	6.621	6.621	0.00000	6.621	6.623	6.622	0.00200
5	6.616	6.617	6.616	0.00100	6.615	6.616	6.615	0.00100	6.615	6.614	6.616	0.00200
6												
7												
8												
9												
10												
Totals	33.09300	33.09300	33.09400	0.00700	33.09100	33.09200	33.09000	0.00500	33.09100	33.09100	33.09100	0.01000
Means	6.618600	6.618600	6.618800	0.00140	6.618200	6.618400	6.618000	0.00100	6.618200	6.618200	6.618200	0.0020
	X1	X2	X3	RA	X1	X2	X3	RB	X1	X2	X3	RC

XA= 6.618667 XB= 6.618200 XC= 6.618200

TEST FOR STATISTICAL CONTROL OF RANGES

0.0044 3

R1= 0.00147 UCLR = 0.00378

2.574

CONTROL

Range max = 0.003 0.003 ≤ 0.00378

The measurement system **is stable**

CAPABILITY (MEASUREMENT VARIATION)	**REPEATABILITY** (GAUGE VARIATION)	**REPRODUCEABILITY** (BETWEEN OPERATOR VARIATION)
	0.00147 1.693	6.6187 6.6182 0.0005
Smv= 0.00090 6 Smv= 0.00540	Sgv= 0.00087 6 Sgv= 0.00520	Sov= 0.00024 6 Sov= 0.00147
		0.0005 1.908
18.00%	17.33%	4.89%

Tolerance	0.0316	0.0315	0.0314	0.0313	0.0312	0.0311	0.0310	0.0309	0.0308	0.0307
Capability %	17.09%	17.15%	17.20%	17.26%	17.31%	17.37%	17.42%	17.48%	17.54%	17.59%
Tolerance	0.0306	0.0305	0.0304	0.0303	0.0302	0.0301	0.0300	0.0299	0.0298	0.0297
Capability %	17.65%	17.71%	17.77%	17.83%	17.88%	17.94%	18.00%	18.06%	18.12%	18.19%
Tolerance	0.0296	0.0295	0.0294	0.0293	0.0292	0.0291	0.0290	0.0289	0.0288	0.0287
Capability %	18.25%	18.31%	18.37%	18.43%	18.50%	18.56%	18.62%	18.69%	18.75%	18.82%

Tolerance acceptable for Capability under 20%: 0.0271 Inches

FIG : 12 – MSA Study

Post conducting measurement system analysis, Process Capability study was launched a fresh with 100 Pcs and cpk improved (Fig 13,14,15)

	USL	6.630		LSL	6.600																				
Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	6.612	6.613	6.616	6.614	6.613	6.613	6.618	6.615	6.618	6.615	6.617	6.617	6.618	6.617	6.618	6.616	6.614	6.615	6.617	6.613	6.613	6.616	6.610	6.617	6.617
2	6.615	6.616	6.618	6.615	6.612	6.615	6.619	6.612	6.617	6.612	6.617	6.615	6.612	6.613	6.612	6.617	6.616	6.612	6.613	6.612	6.612	6.617	6.615	6.612	6.612
3	6.618	6.615	6.615	6.612	6.615	6.613	6.615	6.617	6.615	6.615	6.612	6.619	6.615	6.615	6.613	6.615	6.615	6.613	6.615	6.615	6.615	6.615	6.617	6.615	6.611
4	6.615	6.614	6.612	6.615	6.612	6.615	6.612	6.619	6.613	6.610	6.618	6.610	6.610	6.616	6.612	6.616	6.612	6.614	6.619	6.611	6.612	6.617	6.610	6.610	6.618
5	6.618	6.619	6.619	6.618	6.614	6.615	6.614	6.617	6.618	6.615	6.612	6.617	6.614	6.617	6.613	6.615	6.614	6.611	6.617	6.617	6.617	6.612	6.618	6.616	6.614
X-Bar	6.616	6.615	6.616	6.615	6.613	6.614	6.616	6.616	6.616	6.613	6.615	6.616	6.614	6.616	6.614	6.616	6.614	6.613	6.616	6.614	6.614	6.615	6.614	6.614	6.614
Range	0.006	0.006	0.007	0.006	0.003	0.002	0.007	0.007	0.005	0.005	0.006	0.009	0.008	0.004	0.006	0.002	0.004	0.004	0.006	0.006	0.005	0.005	0.008	0.007	0.007
	X-2 Bar	6.615	UCLx	6.618	LCLx	6.611	Sigma			0.002		Cpku		2.097		Cpk		2.027							
	R-bar	0.006	UCLr	0.012	LCLr	0	Cp			2.062		Cpkl		2.027											

FIG : 13 – Process Capability Analysis- Post Process Improvements

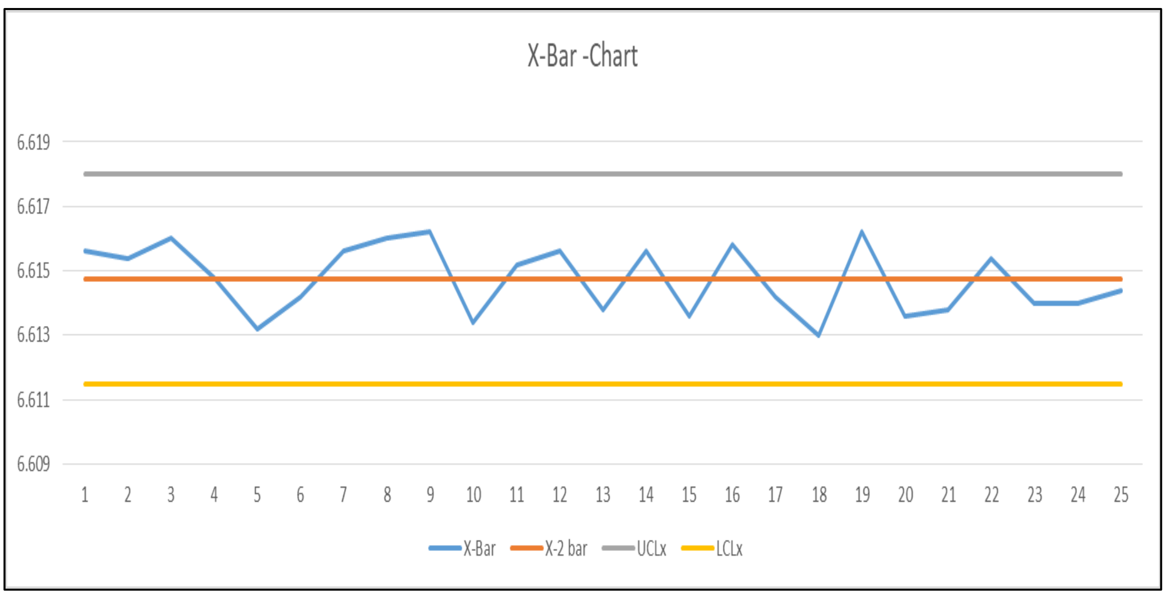


FIG : 14 – X-Bar Chart (Post Process Improvements)

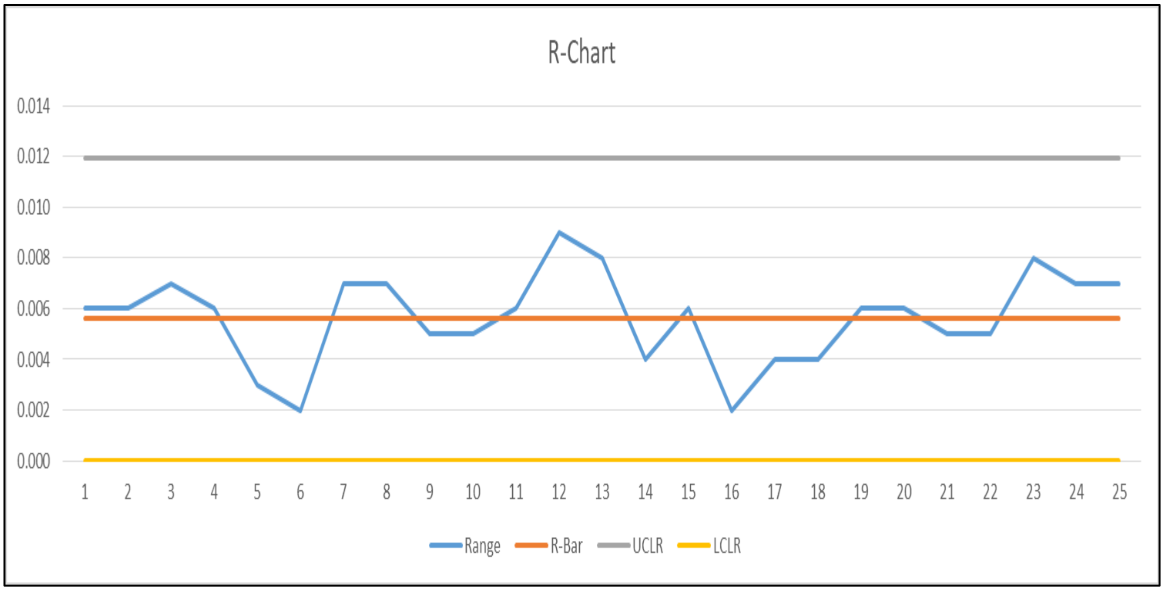


FIG : 15 – R-Bar Chart (Post Process Improvements)

Results & Discussions of Case Study

After the analysis of current state and future state map shown in Figs. 3, 8 and Charts 1, 2 , Process Capability Results as shown in Fig 13, some important findings of the case study are listed below:

- Reduction in total lead time or inventory is reduced from 8.5 Months to 2.8 Months. This means that the customer asking rate can be met in shorter time frame and reduce the cost of capital for the company. Finished Goods inventory however is unchanged as it is customer requirement to keep 1.5 months FG inventory.
- Overall cycle time is reduced from 123 Minutes to 82 Minutes or 33% reduction.
- Quality level is enhanced from 94 % to 98 %
- Number of operations are reduced from 13 to 12
- Number of operators however have increased from 12 to 14. There is an elimination of one operator at CNC milling while as there are three operator additions at NDT checks and at Special coating Processes. The additional in manpower at these processes is due to moving the processes from outsourced to in-house
- Work Balance chart is more evenly balanced now, even though still few of the processes are above Takt time requirements of 6.8 Minutes.

- Process Capability Index Cpk for Key feature increased from 0.589 to 2.207. With the increase in process capability Index, customer confidence in the process has increased and allowed to move on from 100% inspection of feature to sampling inspection. Inspection frequency is reduced to 1 pc in 20 pcs.

- Excess Transportation, Waiting time and defects are reduced

- Outsourced process is now internalized by company and there is better control now as there is reduction in transportation and follow ups.

RECOMMENDATIONS

Aerospace Manufacturing Industry characterized by low volumes, high product mix poses significant challenges to any manufacturing set up. Process Challenges like multiple set ups, stringent quality requirements, non-availability of in country raw material sources being few of them. Through this case study, it is demonstrated that targeted use of the following techniques can be utilized for appreciable gains in speed and improvements in Quality foot print of products and processes.

- Value Stream Mapping (VSM)
- Work Balance Charts
- Process Flow Diagram (PFD)
- Process Failure Mode and Effect Analysis (PFMEA)
- Statistical Process Control Charts (x-Bar, R-Charts)
- Measurement System Analysis (MSA)- Gage R&R

Above tools can be used to reduce waste and improve process Quality. These techniques can be implemented in any department at Aircraft Manufacturing Company.

One caution here is that lean value streams must be developed with respect for people. Respect for people should not be confused with respect for their old habits. Developing lean value streams can be tough, often with one step forward and two steps backward. Developing a value stream exposes sources of waste, which means that people across business functions may have to change their habits. Everyone within an organization has a role to play for successful implementation of VSM and everyone should feel benefits out of the exercise.

One thing which stands out in VSM effort is trust for the people, because it is going to be employees of the organization who can make the success of any VSM event. Other Part features though not critical to customer can be taken up for process capability study and improvement, based on High Risk Analysis using PFMEA tool.

As a last step for sustenance, a Process Control Plan (Fig 16) was established and an internal process audit frequency of once in three months was established for ongoing control. Internal audits are necessary to verify the compliance to established control plan at specified frequency & to ensure control and capability.

	CONTROL PLAN					Date : 24/03/2021
☐ PROTOTYPE	☐ PRE-LAUNCH ☑ PRODUCTION	Key contact Person: Deepak		Control Plan No	CP 30G1425	Date(Org) 24.03.2021
Customer Name	ABC Ltd			CP Rev No	Rev :00	
Part Number/ Latest Change Level	2365179	Core team : Deepak, Raj Kumar, Neeraj Kumar		Customer Approval Date	NA	Date (Rev)
Part Name / Description	Bleed Valve			Other Approval Date :	NA	
Supplier Plant	XYZ, Ltd	Prepared by:	Deepak	Approved By:	Surinder Kumar	

Part / Process No	Process Description / Operation	Machine, Device, Jig, Tools		Characteristics			Special char. class	Product / Process Specification /Tolerance		Methods							
		Mfg	Number	No	Product	Process		Upper Limit	Lower Limit	Evaluation /Measurement Techniques	Sample: Size	Sample: FAI Freq	Sample: Prod. Freq	Least Count/ Uncertainty MM/Inch	Control Method	Responsibility	Reaction Plan
20	Hexagonal Punching & CNC Milling	AERO-TM-7		-	Visual	Hexagonal Punching & CNC Milling	-	VISUAL INSPECTION		Visual	EB	100%	100%	-	Setup Approval Report (IMA-QA-FF-09) / Inprocess Inspection Report (IMA-QA-FF-02) X-Bar R-Chart and Process Capability Calculation after every 100 Pcs	Quality Inspector	Quarantine the Part & raise Non-Conformance & Corrective Action Report IMA-QA-FF-06
					UOS BREAK EDGES .076-0.152		-	0.1520	0.0760	VMS	EB	1	50	XY:- ±3.0+(L/100)µm z:- ±10+(L/100)µm		Quality Inspector	
				KEY	DIA : Ø6.615 ± 0.015 mm		-	6.6300	6.6000	DIGITAL MICROMETER (USE 1 MICRON MICROMETER)	EB	1	20	0.001 mm		Quality Inspector	
					CHAMFER ANGLE 45°±4°		-	49°	41°	VMS	EB	1	50	XY:- ±3.0+(L/100)µm z:- ±10+(L/100)µm		Quality Inspector	

If any Non Conformance is observed during the process operators are instructed to stop the process and bring it to the notice of higher authorities immediately.

SETTING APPROVEL=New setting, Change of tool, Collet, Jaws, Speed, Feed or any other change in process / Setup

REPRESENTATION: I.P.I.R = INPROCESS INSPECTION REPORT , S.A.R = SETTING APPROVAL REPORT ,EB = Every Batch

Note:	Cr Critical characteristic as per design	S Significant/ Key characteristic as per process	M Minor characteristic All characteristics that are not marked C /S

FIG : 16 – Control Plan

CONCLUSION

Results of this case study conducted in an aerospace manufacturing organization show that VSM, a lean manufacturing technique was able to reduce inventory, production lead time, cycle time, defects and excess transportation. Process Certification tools on the other hand were used to enhance the process capability of customer designated key feature. These powerful tool not only highlight process inefficiencies, transactional and communication mismatches but also guides about the improvement areas. Through these technique, it was demonstrated, that acting on the process inefficiencies concerning entire value chain benefits organizations. Tangible benefits of using VSM and process certification tools were

- Reduction in inventory by 67.06%
- Product lead time by 67.06%
- Cycle time by 33.33%
- Defects reduction by 4 %
- Inspection Cost Reduction by 83.4 %
- Process Capability Index Cpk increased from 0.589 to 2.207

VSM gives one sight view of all the processes and helps in finding the inefficient and the most efficient process at plant, while as process certification helps to enhance to increase process capability Index of some key part features.

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