Flow-Days Reduction Using Six Sigma Toolbox at Air Force Base Engine Maintenance Center

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Abstract — *When the United States entered World War I in 1917, the U.S. government searched for a company to develop the first airplane engine "booster" for the fledgling U.S. aviation industry General Electric accepted the challenge first and other followed the path in the "Business of War". The claim for jet engines were the boom of the moment and their maintenance became "The Business". The following discussion presented a productivity improvement approach in a Maintenance Repair Operation Center (MRO) and deals with an application of Six Sigma DMAIC (Define, Measure, Analyze, Improve &, Control) methodology in a military repair center ruled by the Federal Aviation Association (FAA). The need for fast production with safety and higher quality is one of the criteria considered to achieve 44% time reduction. The liaison with a non-profit organization put short time deadline where Six Sigma must be analyzed from a management standpoint that takes into consideration the routine of repair and not production line culture.*

Key Terms — *DMAIC, Flow Days, MRO, Six Sigma.*

INTRODUCTION

Compared with manufacturing industries, MRO (Maintenance and Repair Organization(s)), provides a one of a kind challenge. The complexity of work scopes for a "just in time production" (JIT) put the repair operation in the need for improvement, not just to comply with the demand, but also to maintain aircrafts in flight. MRO accounts for the minimum amount of down-time from beginning to end, which represents the time from taking a plane out of service, disassemble, repair, reassemble, and deliver. Due to the downtime cost, shareholders consider that improvement methodologies must be implemented in the current process. The Six Sigma DMAIC model and SIPOC (Supplier, Input, Process, Output, and Costumer) were selected as primary tools to achieve 44% time reduction of the current flow. The research will be focused on the application of the Sigma tool, but it will also consider Lean tools such as KANBAN and VSM (Value Stream Mapping). Most of the study takes place in a military facility managed by the United State Air Force (USAF) [1], which is partnered with a civilians' work force. The goals are but not limited to the following:

- Reduced lead times for production at shop floor.
- Reduce Work in Progress (WIP) material inconsistency.
- Less inventory, especially work in process inventory.
- Deploy improvement events in compliance with FAA and AFBC (Air Force Base Criteria).
- Create Logistic support cells for higher time consumables areas.
- Increase and maintain a high level of quality.

Research Description

Engine Maintenance Center (EMC) production improvement requires reducing cycle time from 99 days to 55 days. The suggestion of second and third shift implementation to comply with the demand was rejected from higher level management. Overtime and other shop floor work assignation were putted out of the page after FAA in house review. The approach must be directed to the major level of the MRO defined as: Gate 1, Gate 2 and Gate 3 (Figure 1).

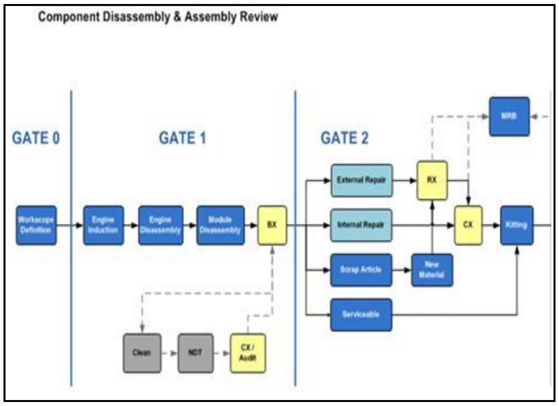

Figure 1
EMC MRO Level Map

Research Contribution

The investigation discussed in this paper will improve the material logistic configuration at the EMC located west of the United States. The research supports the USAF goal on delivery time that reduces considerably the FAA's complaints related to engine repairs and maintenance performance. The results will build a standardized process that will positively impact the inventory, disposition and the repair execution process.

Customer

The direct customers related to the research are mentioned below:

- Engine Maintenance Center (EMC)
- United State Air Force (USAF)
- Air Logistic Service (ALC)

Customer Perspective

The perspectives are mentioned below:

- CTQ- Quality of inputs must be good (Customer-Operation)
- CTC- Inventory Carrying Cost must be minimum (Customer- Finance)
- CTD- On-Time delivery of material to production(Customer-Operation)

Literature Review

The emphasis of on-time delivery and less turnaround time, open door for improvement in all level of the current industries. In this particular case the aerospace which is consider a CTQ from top to bottom. Below discussion of the major point consider for improvement on aerospace plant on the west side of USA.

Description of Maintenance Center

Engine Maintenance Center supports military customers with a broad range of expert services designed to be deployed quickly and reliably. It was no mistake that EMC was the first aviation defense contractor during World War II to be awarded the prestigious Army-Navy "E" for Excellence [2]. EMC understood that individual lives and national security depend on the unflinching support and service of the engines, from on-site overhaul and repair, to extensive customer training and support equipment services, in order to support the military and its aircraft missions. Work performed at the shop consists mostly of on-condition maintenance, meaning when field personnel determine an engine is not operating as efficiently as possible or there is something physically wrong with it, the engine is sent in for repair [2].

EMC covers the twelve major engine build groups and the sections which make up the engine requested to repair. A Build Group is defined as the largest convenient assembly of engine details that can be removed or installed to expedite access to, or buildup of, the engine. This Build Group concept allows the most appropriate sectionalization of the engine based on the desired degree of replacement or repair. The MRO shop divides the repair work loads in three different levels (Figure 1) which are:

- Gate 1- Represents the induction of the desired repair. This level consist of the induction, disassemble and inspection of each component and hardware subjected to removal or repair.
- Gate 2- This level is named as the supplier cycle. This gate contemplates the repair partnership with an approved FAA supplier.

Also, it establishes the internal repair requirement and development of the component. The process in this gate involves buying non serviceable parts and the returning inspection considering quality assurance.

- Gate 3- Includes all steps related to product assembly and final inspection prior to delivery. The level maintains consistency on record and gives a path to test the product.

EMC is considered one MRO partnership, which supplies repair instructions, engineering support, supply chain management and repair. The current EMC consist of 34 A&P (Aviation and Power Plant) certified mechanics, five QA Inspections (Quality Assurance), five engineering and management personal. The area designated for production consists of eleven work cell (Figure 2), one tool crib, one kitting area, one QA clinic and one inspection area (Figure 3) expected to matures meanwhile engines are fixed on a competitive timeframe.

Figure 2
EMC Current Disassembly Area Layout

Six Sigma

Six Sigma is considered one of the disciplines that eliminate defects in any process. According to Devane [3], sigma basic value is the principle for process improvement, statistical methods, a customer focus, attention to processes, and a management system focusing on high-return improvement projects based on continuous improvement and significant financial gains. However, over the past few years, Six Sigma has evolved to be more than a simple statistical definition [4]; the methodologies have become a complex quality improvement that can be applied, not only to a manufacturing industry, but also to any other business where total quality management (TQM) is required.

The approach used in Six Sigma to solve problems is the DMAIC cycle, which stands for Define, Measure, Analyze, Improve and Control. The DMAIC problem-solving methodology is particularly useful when [5]:

- The cause of the problem is unknown or unclear.
- The potential of significant savings exist.
- The project can be done in 4-6 months.

Figure 3
EMC Current Inspection Area Layout

The DMAIC methodology integrates statistical process control (SPC) tools and techniques (Figure 4), including the “Magnificent Seven”, to solve problems and achieve continuous quality improvement in a disciplined fashion [6]. As per George [7], Motorola recognized that there was a pattern too, that could naturally be divided into the five phases of problem solving, usually referred as DMAIC:

- Phase I: Define: The purpose of this phase is to clarify the goals and value of a project.
- Phase II: Measure: The purpose of this phase is to gather data on the problem.

- Phase III: Analyze: The purpose of this phase is to examine the data and process maps to characterize the nature and extent of the defect.
- Phase IV: Improve: The purpose of this phase is to eliminate defects in both quality and process velocity.
- Phase V: Control: The purpose of this phase is to lock in the benefits achieved by doing the previous phase.

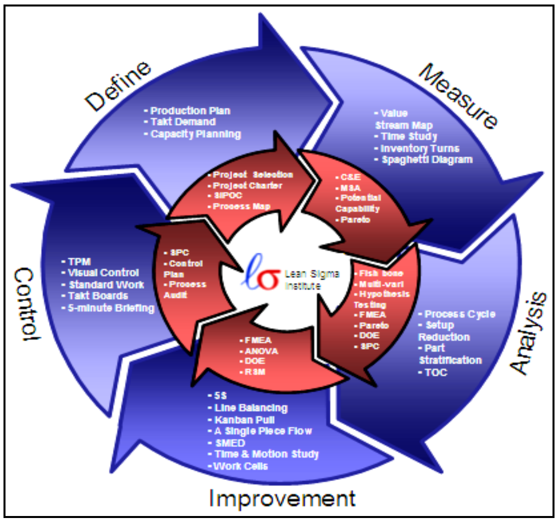

Figure 4
DMAIC Method
(Lean Sigma Institute, February 2011)

With the Six Sigma overall strategy, an organization can not only achieve near perfect quality using the DMAIC methodology (Figure 4), but also attain superior availability, reliability, delivery performance and service in any process [4].

Lean Tools and Techniques

The Lean management toolkit includes a number of tools, techniques and practices that enable and facilitate the implementation of Lean. [6]. The SPC tools and techniques used in Six Sigma are also part of the Lean management toolkit. Lean tools and techniques include KANBAN and VSM, besides 5S.

- **"KANBAN"**
  KANBAN means "signboard" in Japanese. The definition has broadened to signify a tool used to effectively control the flow and the quantity of parts in production. In this system, when an operator needs parts for a certain process of the production line, he writes the details of the parts needed and the quantity needed. He then takes this card to the preceding process to withdraw the amount needed [7].
- **Value Stream Mapping**
  A VSM is the set of activities that contributes value to the customer. Value stream mapping is a method for showing the material and information flow in diagram form. The map captures process, material flows, and information flows of a given product family. Also, helps to identify waste in the system considering activities that do not contribute to value to the customers.

METHODOLOGY

As result of consolidation of operations and significantly increased production requirements, EMC is facing bottlenecks in supply versus demand. In order to achieve a 55 days process an improvement needs to be taken into consideration. The first approach must be to find the bottleneck, considering Six Sigma phase 1 "Define". Then the "Measurement" phase by conducting a short assessment to confirm the bottleneck, continued by VSM and time consumption analysis that opens EMC for improvement. The "Analyzing" phase will introduce the Pareto Chart, where measures will become visual and solutions will be brainstormed. Under the "Improvement" lean/sigma tool combination, for example KANBAN, 5S and Mistake proofing will challenge the system to drop 44% of cycle time and increase the EBIT (Earnings before interest and taxes) of EMC. Finally, the "Control" phase will involve audit, report and visual control that eliminate the bottleneck and waste of the current configuration, and, of course, will sustain the change.

Applying DMAIC

In order to apply DMAIC the step mentioned below must be follow:

1. **Define Phase:** Six Sigma makes use of facts and figures while initiating quality improvements in business processes, it greatly increases the probability that the implementation project will turn out to be a huge success. However, since there are often just too many variables to consider, the best way to create boundaries and concentrate on flow days' reduction from 99 days to 55 days is by defining the problem and how it will be approached.

   - **Development of a Project Charter:** This phase determines the objectives & the scope of the project, collect information on the process and the customers, and specify the deliverables to customers [3]. Table 1 presents the team charter for the project, explicit description of situation and goals.
   - **Creation of a Problem Statement:** Defining a problem with a Problem Statement is common in Six Sigma methodologies. However, the project needs something shorter and simpler that maintains the group's focus. To establish the EMC problem statement a comparison between the current and desired state was debated. The results of the brainstorming establish that: *"The EMC MRO has a disconnection between Gate 1 (Disassemble),* Gate 2 (Kitting) and Gate 3 (Assemble) processes and will not be able to comply with the requirement of 55 days production if the current system is not improved".
   - **SIPOC Diagram**: To comply with the requirements, the shop needs to evaluate different methodologies in considering further certification of Federal Aviation Association (FAA) and Air Force Base Criterion (AFBC). A SIPOC diagram will help the group to understand the customer and what needs to be considered. Table 2 illustrates the SIPOC related to flow days reduction initiative.

Table 1
Project Team Charter

Project Team Charter	
Black Belt Name:EMC Engineering,Material and Operation Dpt	Champion Name : AFB,Operation
Project Start Date : June 23, 2011 Project Completion Date : Dic. , 2012	Project Location : AIR FORCE BASE ENGINE MAINTENANCE CENTER, West USA
Business Case: The Engine Maintenance Center (EMC) represents one of the biggest mechanical shops dedicated to the repair and test of the United State of America (USA) Air Force (AFB). As result of the military mobilization on the past few years, the management requests the reduction of the shop flow days from 99 days to 55 days. To comply with the requirement the shop needs to evaluate different methodology considering further certification of Federal Aviation Association (FAA) and Air Force Base Criterion (AFBC)	
Project Title: FLOW DAYS REDUCTION AT AIR FORCE BASE ENGINE MAINTENANCE CENTER	
Stake holders: AFB, PP	
Team Members:Employees of EMC Engineering,Material and Operation Dpt	
Project Milestones : Target Completion Objectives (Quality, Delivery, Cost): Delivery of 100% complete documentation Target Completion Date: 12/21/2012 Process Review Date: 1/23/2013 Process Owner: ECM	

Table 2
EMC SIPOC

EMC SIPOC Analysis
Rev. 27 April 2011 /jbr

Suppliers	Inputs		Process	Outputs		Customers
	Description	Quantified measure		Description	Quantified measure	
LPM	Engine / Hardware	Available	Gate 1 (Induct, RX, Dissy & BX)	Dispositioned parts	CTQ : Complete by 18 working days from Induction	PW F117 HMC
OC-ALC	Tooling & Fixtures	Available				
	Mechanics	Trained to need				
Engineering	Work Instructions	Accurate and on-time				
LPM	Replenishment Parts (Other Direct)	Parts available when needed	Gate 2 (Replenishment)	Kit Cart	100% complete	OC-ALC
Outside Vendors	Repaired Parts	Parts returned serviceable on time				
OC-ALC & P&W QA	Dispositioned parts	Accurate				
OC-ALC & P&W QA	Inspection Equipment	Available				
	Inspectors (CX)	Trained to need				
Logistics Cell, Warehouse & Quality	Manpower	Trained and Available				
Supplier Management	Buyer Expedite Function	Trained to need				
Operations	Replenishment Parts (Kit & Bin)	Parts available when needed				
Gate 1 & 2	Dispositioned parts	Accurate	Gate 3 (Assy & Ship)	Serviceable Engine	CTQ : Complete by 20 working days from Gate 3 Start	LPM
Gate 2	Replenishment Parts	Available				
OC-ALC	Tooling & Fixtures	Available				
	Consumables (Chemicals)	Available & Correct				
	Mechanics	Trained to need				
Engineering	Work Instructions	Accurate and on-time				

2. **Measure Phase:** This phase presents the details of process mapping, operational definition, data collection chart, evaluation of the existing system and the assessment of the current level of process performance at EMC [3].

   - **Process Map:** The current state of EMC establishes three different levels: Gate 1, Gate 2 and Gate 3. All the levels have internal procedures; for example Gate 1 contemplates the work instruction release (permission and instruction to execute disassembly and inspection), disassembly of hot area and disassembly of cool area. The first level, according to the time study, takes approximately 29 days, which includes the receiving days, the parts removal, and the inspection of the parts. The current inspection procedure is performed using hard copy instructions related to the part number of each part. On the other hand, Gate 2 defines the supply chain of the process, were the turnaround time (send-receive) established for a hot component is 25 days. Supplier and vendor procedures are not related to the shop, this means that there is no way to decrease their time, it is enough to create a shipping request alert. The effects of parts not removed on time at Gate 1 evidently create assembly delays in Gate 3, but the final level has its own issues. Gate 3 is identified as the filter; parts not inspected in Gate 2 create time constraints on this gate besides the assembly procedures which consume time on fit and tolerance measurement. Figure 5 illustrates the current process by area and personnel in charge.

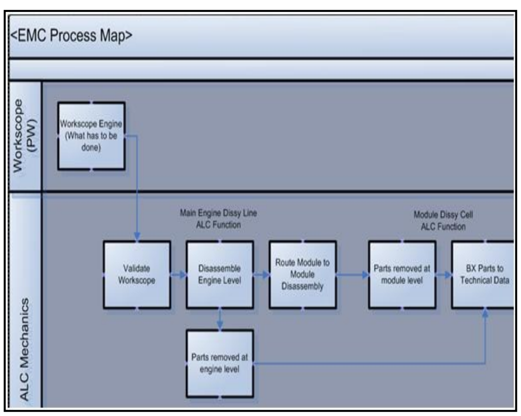

Figure 5
EMC Process Map

- **VSM**: The current EMC value stream mapping (Figure 5) captures time before Gate 1 and after Gate 3. These values are considered based on FIFO (First in- First Out) rules and evaluated to eliminate waste at each stage. For example, Gate 1 is missing time just on communication alone (disconnection between management and manpower). Also, time is consumed in tool search, unfamiliar instructions or lack of instructions, non-designated inspection points and disassembly areas. Gate 2 is directly affected from the time consumed to inspect components and for third party companies. Finally at Gate 3 the time loss is basically due to searching for parts, measurement definition, tools unavailable, and points for assembly, QA inspection, record tracking and compliance verification. All the major offenders are illustrated in Pareto Chart (Figure 6). The time consumed by each operation was calculated using MTTR (Mean Time to Repair) analysis (Figure 7). The analysis shows the current time delay for each step of each gate.

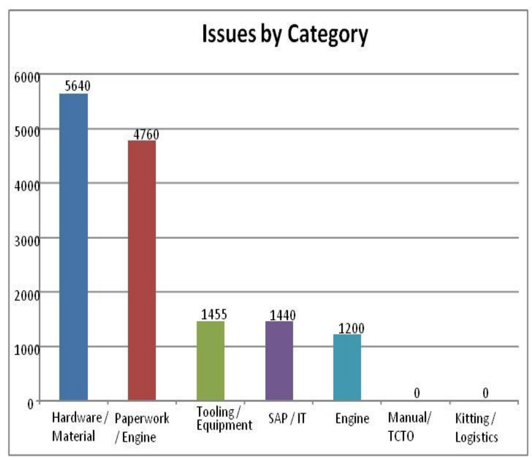

Figure 6
Pareto Chart November 2011

3. **Analyze Phase:** The analyze phase determines the root causes of poor performance. The Pareto Chart (Figure 6) gives a visual illustration of the issues EMC is passing through.

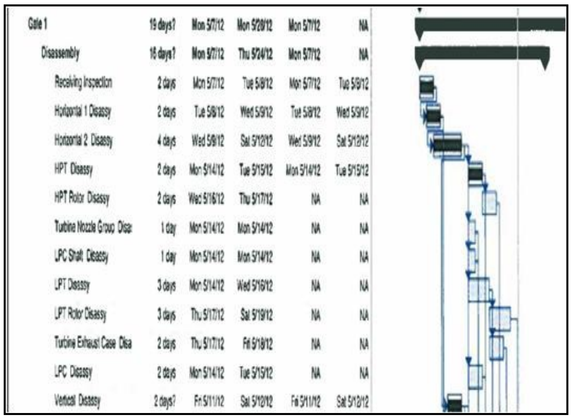

Figure 7
EMC MTTR November 2011

According to the chart Material is number 1, followed by Instruction, and Tooling. In order to determine why Material is the major offender, the team executes different analysis.

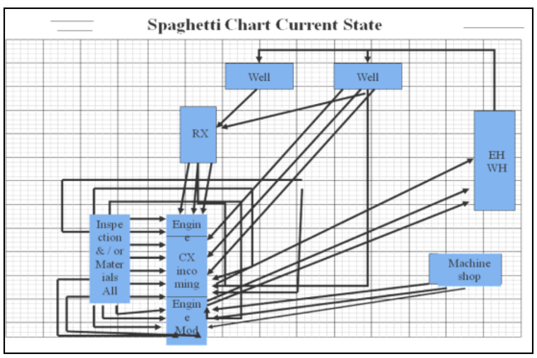

Figure 8
EMC Current Material Spaghetti Chart

The first execution was the Material Spaghetti Chart (Figure 8), that shows how components move around without any pattern, the lines indicate where the material gets disassemble or inspected and it is wrapped up in the Material area. All components pass through inspection at least 2 times before the final stop at the material shipping area. The treatment of the missing Gate 1 due-date opened space to utilize another tool called the cause-and-effect diagram (Figure 9). This process identifies sources of problems and organizes the relationship between the variables. In this particular case the neglect of Gate 1 is caused by three different variables. The first one is the lack of training; mechanics are not related to assigned task. The second cause is that the tooling unavailable: the tooling is used in multiple locations (Disassemble and Assemble area). The third cause consists of data validation; the current process was evaluated on one engine repaired on a 99 days turnaround time.

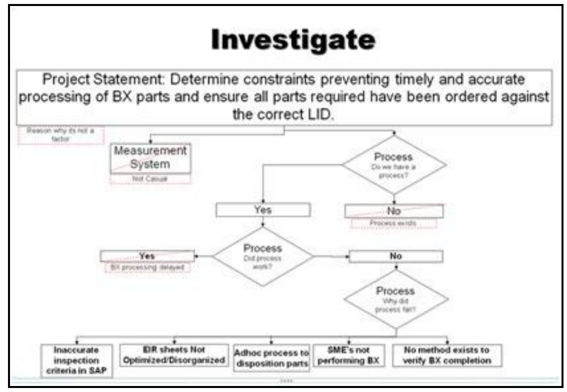

Figure 9
EMC Cause-And-Effect Diagram

The use of this data will allow only the technical improvement of manpower and not the automation part of it; the production depends a lot on the accuracy of the removal and not in trial and error processes. The interpretation of the data allows the team to proceed with Likely & Controllable Causes analysis (Figure 10) in the inspection portion of Gate 1. The analysis identifies that the data provided for inspection is contradictory and affects the time between serviceable and scrap decisions, putting the Gate on hold.

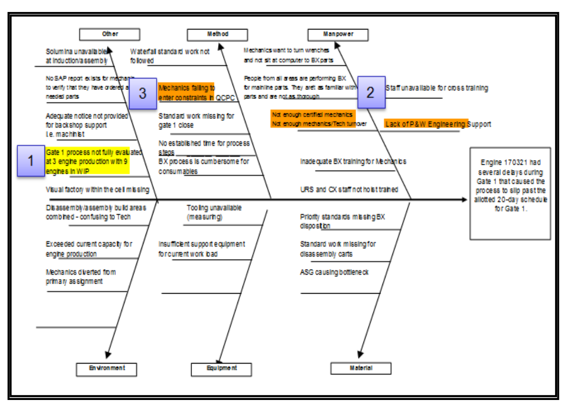

Figure 10
Inspection Likely & Controllable Causes Analysis

4. **Improve Phase:** The team members generated ideas for improving the process. The idea is analyzed and evaluated to select the best potential solutions in order to be planned and implemented [2]. For example, the EMC improvement team decides that the best way to achieve the 55 days turnaround time is attack Gate 1 to win time upfront and reorganize Gate 3 to assemble faster. Gate 2 will be evaluated using customer satisfaction feedback analysis, which puts the supplier on auction for repair down-time, pricing and quality. Some of the tools used in the improvements for Gate 1 and Gate 3 are: Water Fall, Technical approach, Work Cell Reorganization, Kanban and 5s.

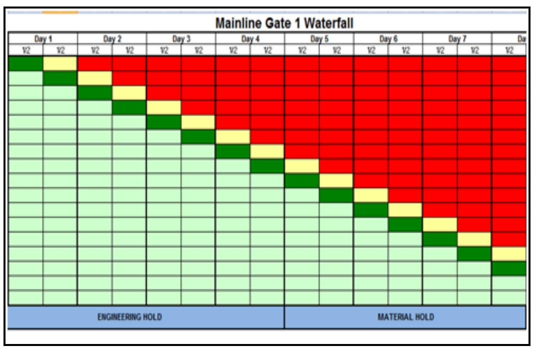

Figure 11
EMC Waterfall Charts

- **Waterfall**: Waterfall charts are diagrams that let you visualize data that is generated cumulatively and sequentially across a process [9]. EMC implemented a tracking procedure for each face. The chart (Figure 11) gives a visual timing and work stoppages at all gates, but direct criteria on Gate 1.
- **Technical approach**: In accordance with the Likely Analysis the inspection criteria de-accelerated Gate 1 completion days. Considering a fully automated improvement the EMC team put into practice the use of Systems Applications Products (SAP). Workflow ensures that the right work is addressing the correct part. This tool accelerates the inspection process by 45% eliminating redundant inspection and creating a tracking procedure for material. Figure 12 shows one of the screens utilized to inspect parts; this screen shows the limits for serviceability.

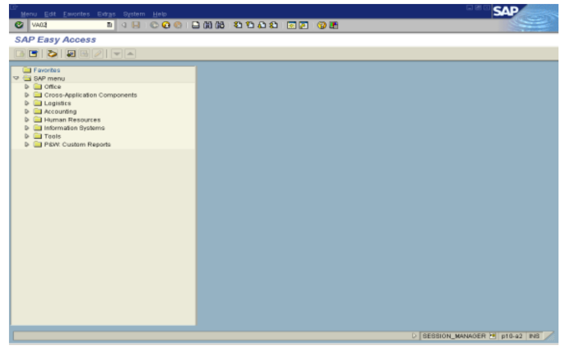

Figure 12
EMC SAP Screen

- **Work Cell Reorganization:** The efficiency of production depends on how well the various machines, production facilities and employee's amenities are located in a work area. Only a properly laid out plant can ensure the smooth and rapid movement of material [8]. EMC shop implementation of the relocation of tooling and engine positions (Figure 13) is able to improve the disassemble and assemble flow. This approach allows the MRO to execute multiple tasks in multiple engines, subtracting time from Gate1 and Gate 3.

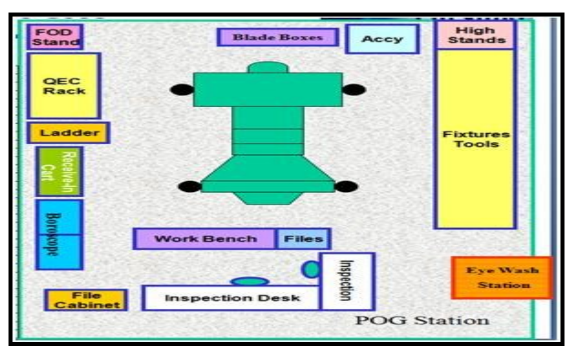

Figure 13
EMC Tooling and Engine Relocation

- **KANBAN:** The high degree of work scope mix makes it difficult to create a pure one piece flow environment. Therefore, a pull system is generally the best solution to visual material flow control. The EMC considers that the disconnection of Gate 2 to receive material makes a bottleneck at Gate 3, reason for which the motor pull was implemented. The current areas were labeled and routed in order to improve the pickup of material (Figure 13) reducing days of searching and shipping component.

- **5S:** 5S promotes a visual and efficient workplace as well as a 'refreshing' environment to both associates and visitors. Benefits of 5S are seen in the production area (Figure 13); in the visual management of certain areas, such as tooling and disassembly, there is a decrease in time on Gate 1 from 2 days of tooling organization to 30 min for use and stock.

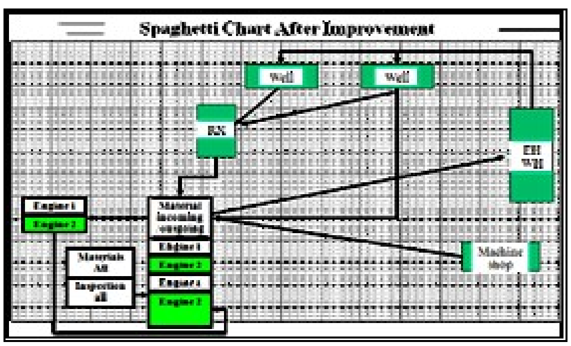

Figure 14
EMC Future Material Spaghetti Chart

5. **Control Phase:** This phase is about holding the improvements achieved by the project team. The control on the EMC will be performed by conducting a periodical review of the new progress considering the impacts in the overhaul system. All the changes addressed in the improvement phase have being documented in the training material to ensure that all employees are aware of the new process. The standardization of other process has being addressed on standard work and the improvements are measured by the EBIT and COPQ reports.

Results and Discussion

The Six Sigma based methodology has been used to optimize the EMC operational procedure. The results obtained after implementing the improvements were measured in categories for MRO:

- Cost/benefit impact – COPQ of EMC reduced from 1.8% 2011 to projected 1.3% for the 2012Q1. This reduction represents the adjustment of Gate 1 inspection level, by the SAP improvement. The new flow or serviceable part acquisition, reduction gate 1 to 15 days. Also, the management of material using motor pull system generates a 25% saving in the 2011 Q1, basically by reduction the inventory, the scrap part and the higher fees by demand (Figure 15).
- Customer satisfaction impact – Customer satisfaction is achieved by providing the products and service of right quality, in the right quantity at the right time, right place and right cost [2]. The reorganization of the shop, the visual management of tooling and the production tracking illustration provide the EMC a customer feedback of 5 in a scale of 6.

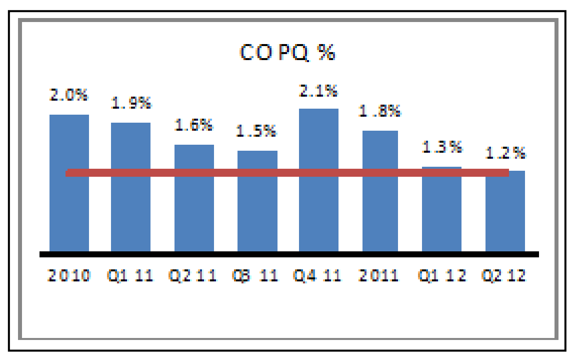

Figure 15
EMC COPQ Actual and Plan

- Time impact – Considerable time is saved by eliminating non-production (idle) time and by not producing the defective product, the EMC last executing present a 65 turnaround time, just by implementing reorganization and inspection automation.

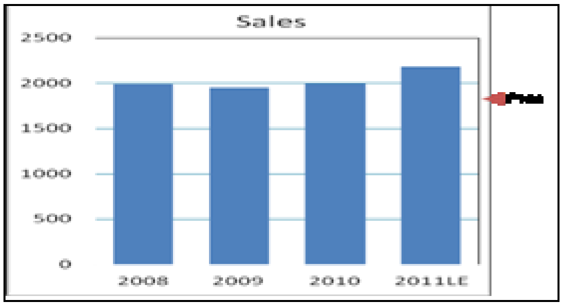

Figure 16
EMC Actual Supply Saving and Plan

- Improvement in productivity – Time saved from reworking is time utilized to improve Gate 2 (Kitting properly). The productivity picks up by reduction the waste on the material handling (Figure 14). Higher demand, lower cost of production and optimize supply chain.
- The change in configuration and implantation of accurate system as SAP, Kanban and Production metric help any production system to succeed. The EMC MRO shop projects to increase sale by 10% (Figure 17) in 2012, open a door to incorporate more lean but now considering the improvement of storage and delivery system.

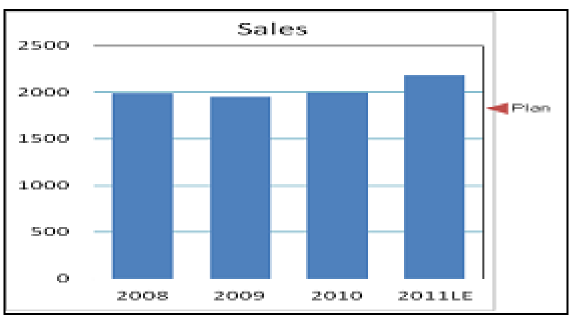

Figure 17
EMC Sales

CONCLUSION

The use of the Six Sigma methods can yield impressive results. The methods improve engine care, maximize resources/equipment and also increase productivity and execution on the user/train interaction. Figure 16 and Figure 17 show the improvements achieved when Sigma is incorporated on a MRO production. The flow of material, the repair station and the time consumed is reduced, giving higher profit on a daily basis. The integration of new systems compatible with the shop layout gives a path to visual organization (Figure 13) where the removal flow and the material gets shipped on time. The control of the process measured with the approach of the waterfall matrix (Figure 10) offers the stakeholder the security that the flow-days reduction is almost real. The application of Lean and Six Sigma demonstrates that the delivery of more simplicity can reduce engine downtime and place it in an achievable timeframe of 55 flow-days.

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