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Simulation Program Based on Lean Six-Sigma to Improve the Performance at Airplanes Depot Line Workshop (A Case Study Applied at Airplanes Structure Repair & Depot Line Workshop)

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Abstract— Scientists of management have been classified and named the systems that work in Space Shuttle, Nuclear Power and Aviation field as a complex and critical systems. In this situation, maintenance and improvements can be supported by an approach which adapts methodologies and tools (Requirement Management).Man, products and business itself are the valuables in aviation field. Therefore airplane (A/P) maintenance systems has been classified as complex and critical systems because of risk always around also the environment that compromised the accuracy, security, and Completeness of information and high level of technician's training.
The high cost of systems support, airplanes maintenance and pressure to eliminate waste without adding risk to the operation is forcing Airplanes maintenance companies to look at maintenance in a new way to improve performance and avoid loss of business.

1 Introduction

Man, products and business itself are the valuables in aviation field. Therefore, airplanes (A/P) maintenance systems has been classified as complex and critical systems because of risk always around also the environment that, compromised the accuracy, security, completeness of information and high level of technician's training. "ABC Company" which specialized in providing maintenance and overhaul of type (F) airplanes, although the "ABC Company" implements Total Quality Management (TQM) according to, the international standard ISO 9001:2008 requirements there are:

- External customer complaints related to the delay of on-time A/P delivery to the customers
- Internal customer complaints related to high A/P maintenance and overhaul process cycle time and cost
- Internal customer complaints related to applying the company's management system documentations and complexity of airplane's working documents

Study Methodology

There are three basic types of research design, explained in figure (1).

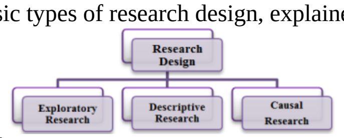

Figure (1) Types of Research Design

We used the following methodologies:

- The exploratory research.
- The descriptive research.
- The objective of causal research which include the following:
  1- Collect and analyze data at "ABC Company" related to the A/P maintenance and overhaul process.
  2- Using an integrated approach of Lean Six-Sigma Methodology with (I.T). A schematic representation is, explained in figure (2).

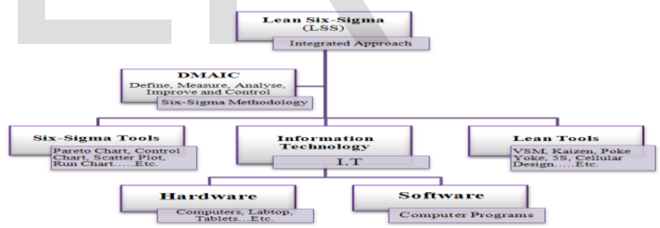

Figure (2) Schematic Representation of Lean Six-Sigma Methodology Integrated with (I.T)

Data Collection and Analysis

The data sources include the following: the company documentations, Brainstorming, Literature review, books and articles, Historical data, Qualitative and quantitative data and customer's surveys.
The data analysis techniques include the following: mean, Variance, standard deviation, Target, Pareto chart, Control chart, Run chart, Pie chart, Bar chart, Time Series Plot, Drill down tree diagram, Process flow chart, Cause and effect analysis and Value stream mapping.

Study Limitations

The study conducted at the A/P Str. Repair & D. Line Workshop in "ABC Company" on type (F) airplanes. In accordance to, (DMAIC) Methodology, the paper was, divided into five main studies (Define, Measure, Analyze, Improve and Control) as explained in table (1).

Table (1) The paper Time Periods

#	Research Procedure	From	TO
1	Define Phase	1/1/2011	6/7/2011
2	Measure Phase	7/7/2011	4/1/2012
3	Analyze Phase	5/1/2012	1/7/2012
4	Improve Phase	2/7/2012	2-3-2013
5	Control Phase	4-3-2013	1-6-2013

"Literature Review of Lean Six-Sigma

Historical Development that Led to Lean Six-Sigma Methodology

The historical development of Quality improvement methodologies in the twentieth century has been, studied in figure (3).

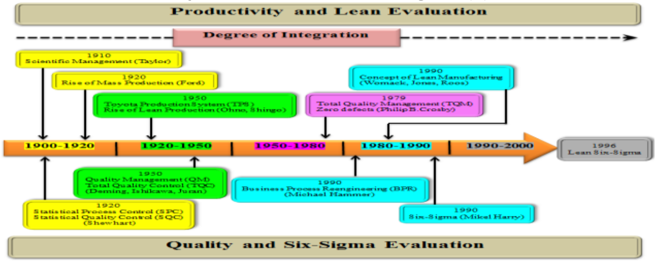

Figure (3) Historical Development that Led to Lean Six-Sigma Methodology

Lean

Lean is, linked to speed, efficiency, and elimination of waste. The goal of Lean is to accelerate the velocity of any process by reducing waste in all its forms.

Lean Thinking focuses on value-added flow and the efficiency of the overall system. Lean Manufacturing is a manufacturing philosophy that shortens the time between the customer order and the product build/shipment by eliminating sources of waste. The eight wastes described in figure (4).

Figure (4) Eight Wastes in Manufacturing

1- Over production 2- Producing defective products
3- Inventories 4- Motion
5- Over processing 6- Transportation
7- Waiting 8- Unused talent

Lean Tools

Lean tools may help you to maintain the improvements you achieved. Table (2), explains the meaning of some Lean tools.

Table (2) Lean Tools

Lean Tool	Definition
Value Stream Mapping (VSM)	The process of creating a visual map of the value stream in order to, show the flow of materials and information. They include information on Takt-Time (demand rate), inventory levels, changeover times, and manpower.
Five-S (5S)	5S is the abbreviated reference to five Japanese words that govern workplace organization and housekeeping. The S refers to the first letter of each element. The basic idea is a place for everything and everything in its place. An ordered workplace helps to improve overall efficiency, by eliminating waste. 5S can be-translated into the following five words: Housekeeping, Workplace Organization, Cleanup, Cleanliness and Discipline.
Cellular Design	Design of production or service process that links all operations in close proximity so that, visual signals can be-used to control production.
Standardized Work	This is one of the key components of a Just-in-Time (JIT) production system (Lean). In order to achieve a balanced work flow, cycle time equal to Takt-Time, and high Quality, work must be standardized at all operations for optimum efficiency and consistency.
Error Proofing (Poka-Yoke)	The design and implementation of fail-safe mechanisms to prevent a process from producing defects. The emphasis here is on error prevention rather than resolution, where efforts are-made to reduce or eliminate the opportunities for committing errors. This is often done by reducing the number of steps in the process or the number of parts in the product.
Cycle-Time (CT)	The time elapsed from the start to the end (one cycle) of an operation. It is the time taken to complete processing of a single unit of a product/transaction and includes the time consumed by all activities within the process area including product/service creation or transformation, wait time, transportation, and rework.
Takt-Time	The time it should take to produce one unit if production is-matched to demand. It gives the pace of customer demand. Takt time = net available production time (after breaks) per period divided by Average customer demand during that same period.

Six-Sigma (SS)

Sigma is the letter in the Greek alphabet used to denote standard deviation, a statistical measurement of variation, and the exceptions to expected outcomes. Table (3), explains an abbreviated summary of Sigma-Level, Defects per Million, and Yield, or success rate of the outcomes. You can identify your level of Sigma performance and then compare it to the chart in figure (5), which explains the relationship between percent acceptable and the Sigma-Level.

Table (3) Sigma-Level

Sigma	Defects per Million	Yield %
6	3.4	99.9997
5	233	99.977
4	6,210.00	99.379
3	66,807.00	93.32
2.5	158,655.00	84.1
2	308,538.00	69.1
1.5	500,000.00	50
1.4	539,828.00	46
1.3	579,260.00	42.1
1.2	617,911.00	38.2
1.1	655,422.00	34.5
1	691,462.00	30.9
0.5	841,345.00	15.9
0	9,331.00	6.70

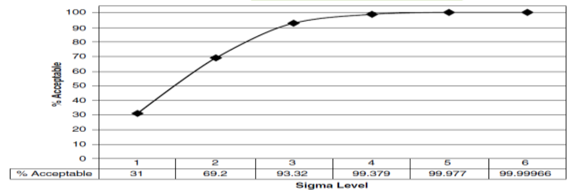

Figure (5) Sigma-Level versus Percent Acceptable

Six-Sigma Tools

Table (4) Definition of Some Six-Sigma Tools

Lean Tool	Definition
Quality Function Deployment (QFD)	A structured method in which customer requirements are translated into appropriate technical requirements for each stage of product development and production. The QFD process is often referred to as listening to the voice of the customer.
Brainstorming	A problem-solving tool that teams use to generate as many ideas as possible related to a particular subject.
Flowchart	Graphical representations of the steps in a process, flowcharts are drawn to better understand processes. The flowchart is one of the seven tools of quality.
Charter	A documented statement officially initiating the formation of a committee, team, project, or other effort on which a clearly stated purpose and approval is conferred. Periodic reviews of the charter with the sponsor ensure alignment with business strategies; review, revise, and refine it periodically throughout the DMAIC process based on data.
SIPOC	Acronym for Suppliers, Inputs, Process, Outputs, and Customer; enables an at-a-glance, high-level view of a process.
Cause and Effect Analysis (Fish Bone)	A visually effective way of identifying and recording the possible causes of a problem and the relationships between them as they are suggested by the team.
Design Of Experiment (DOE)	A branch of applied statistics dealing with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors and noises that control the value of a parameter or group of parameters.
Pareto chart	Quality tool based on Pareto principle. The Pareto chart uses attribute data with columns arranged in descending order, with highest occurrences (highest bar) shown first; uses a cumulative line to track percentages of each category/bar, which distinguishes the 20% of items causing 80% of the problem. It is considered to be one of the seven basic tools of quality.
Control chart	A plot of some parameter of process performance, usually determined by regular sampling of the product, as a function (usually) of time or unit number or other chronological variable.
Run chart	A line graph showing data collected during a run or an uninterrupted sequence of events. A trend is indicated when the series of collected data points head up or down crossing the centerline.
Capability ratio (Cp)	Equal to the specification tolerance width divided by the process capability.
Cpk	A widely used process capability index. It is expressed as a ratio of the smallest answer of: [USL-Xbar]/3sigma or [Xbar – LSL]/3sigma. If the Cpk has a value equal to Cp the process is centered on the nominal; if Cpk is negative, the process mean is outside the specification limits; if Cpk is between 0 and 1, then some of the Six-Sigma spread falls outside the tolerance limits. If Cpk is larger than 1, the Six-Sigma spread is completely within the tolerance limits. A value of 1.33 or greater is usually desired. Also known as Zmin/3.
Histogram	A graphic representation of a frequency distribution. The range of the variable is divided into a number of intervals of equal size (called cells) and an accumulation is made of the number of observations falling into each cell.
Defects Per Million Opportunities (DPMO)	Calculation used in the Six-Sigma process improvement initiatives indicating the amount of defects in a process per one million opportunities; number of defects divided by (the number of units times the number of opportunities) = DPO, times 1 million = DPMO.

Lean-Six Sigma (LSS)

The obvious strengths of Lean and Six-Sigma have been-combined and packaged as (LSS) in order to, give you the best of both worlds, figure (6) and figure (7), describes the benefits of complaining Lean and Six-Sigma.

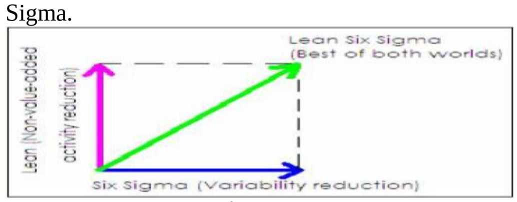

Figure (6) Lean Six-Sigma (Best of Both Words)

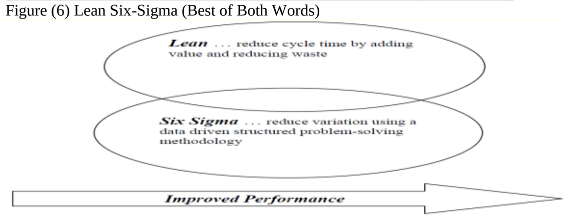

Figure (7) Lean and Six-Sigma Work Together to Improve Performance

Lean-Six Sigma Integration (LSS)

The (LSS) method is, based primarily on the combined Lean Manufacturing Techniques and (DMAIC) Six-Sigma Methodology. Six-Sigma Quality analysis (e.g., reducing process variability) is combined with Lean Manufacturing speed (e.g., reducing process Lead-Time) within the framework of the deploying company's production or service system. Figure (8), describes typical gains from the application of (LSS) to a production or business system.

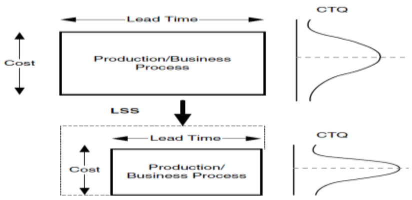

Figure (8) Typical Process Gains from LSS

Differences between Lean and Six-Sigma

Table (5), explains the characteristics of Six-Sigma and Lean Manufacturing.

Table (5) Characteristics of Six-Sigma and Lean Manufacturing

	Six-Sigma	Lean
Goal	To improve process capability and reduce variation	To reduce lead time and process waste
Focus	Process outcomes	Process flow and waste
Philosophy	Variability within specifications is cost	Time in system and overcapacity is cost
Tools	Statistical analyses	Factory physics
Application	Production and business processes	Production and business processes
Approach	DMAIC problem-solving methodology	Value stream mapping and lean techniques
Major measure	DPMO	Lead time
Major driver	CTQs/CTSs	Value-added
Project selection	Problem solving	Continuous improvement
Skills	Mainly analytical	Mainly process knowledge
Gains	Process accuracy and quality	Process effectiveness and delivery speed

Major Elements in (LSS) Approach

An integrated (LSS) approach to process improvement is, expected to include the following major elements or components:

- Developing a current-state (VSM)
- Using a current-state (VSM)
- Applying Six-Sigma (DMAIC) Methodology
- Integrating Lean Techniques into (DMAIC) Methodology
- Applying Lean Techniques as a continuous improvement effort
- Reflecting parametric and structural changes made to the process
- Working intensively on creating a cultural change in an organization toward Six-Sigma accuracy and Lean effectiveness in all business functions

LSS-Enhanced (DMAIC)

A plan is, developed to collect process data and measure process performance, opportunities, and defects. A data-driven and well-structured approach is then, followed to analyze process performance, solve problems, and enhance performance toward the nearly perfect Six-Sigma target.

(DMAIC) starts with:

The Define (D) Step The Measure (M) Step
The Analyze (A) Step The Improve (I) Step
Finally, the Control (C) Step

The five interconnected steps of (DMAIC) are, as explained in figure (9).

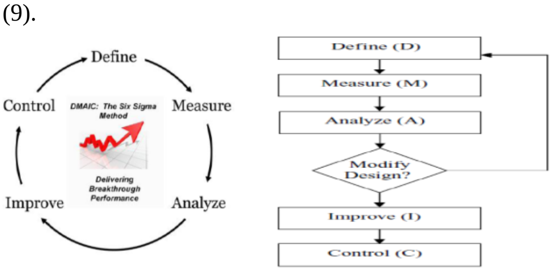

Figure (9) (DMAIC) Process

Table (9), summarizes the tools and deliverables at each (DMAIC) stage.

Table (6) Main (DMAIC) Tools and Deliverables

DMAIC Stage	Tools	Deliverables
Define (D)	Project charter, process map quality function deployment, benchmarking, Kano analysis, etc.	Project objectives, CTQs, design variables, resources, project plan, etc.
Measure (M)	Data collection, sampling, work measurements, sigma calculator	Measured performance, process variation (sigma value), process capability measures
Analyze (A)	Statistical analyses, charts, root-cause analysis, design of experiment, and ANOVA	Defined improvement opportunity, sources of variation, action plan
Improve (I)	Design optimization, robustness, brainstorming, validation	Selection of the best solutions, changes in deployment, adjustments to process variables
Control (C)	Error-proofing, failure made and effect analysis, statistical process control, standards, Pugh analysis	Monitoring plan, maintained performance, documentation, transfer of ownership

Table (7) Utilizing Lean Tools in LSS-Enhanced (DMAIC)

	DMAIC				
	Define	Measure	Analyze	Improve	Control
Lean Tools	Value stream mapping (VSM)	Lead-Time	Work analyses	SMED	Visual controls
		Takt-Time	Flow analysis	JIT-Kanban	Standard work
		Inventory level	Scheduling	Line balance	Kaizen

Proposed Methodology of Lean Six-Sigma (DMAIC) Approach

The proposed methodology of the Lean Six-Sigma (DMAIC) process is as explained in figure (10).

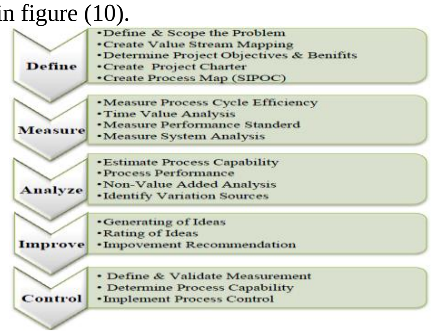

Figure (10) Lean Six-Sigma (DMAIC) Steps

"Airplanes Structure Repair and Depot Line Workshop

Introduction

We explains the A/P major components, focusing on A/P structure major components and the types of (A/P) construction.

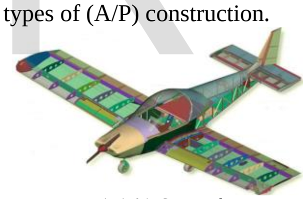

Figure (11) A/P Structural Parts

Airplane Description

The A/P consists of three major components as explained in figure (12).

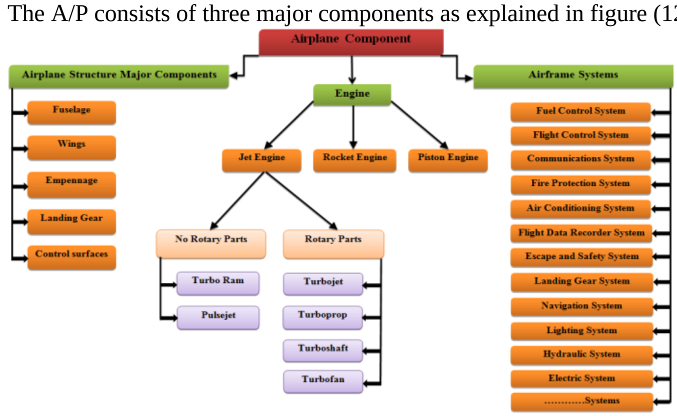

Figure (12) A/P Major Components

Airplane Structure Major Components

The A/P is a device that is, used for flight in the air. Figure (13), describes the five principal units.

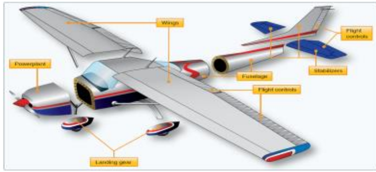

Figure (13) A/P Components

Fuselage

The fuselage is the main structure or body of the fixed-wing A/P. Figure (14), describes the fuselage.

Figure (14) Fuselage

Wings

Empennage

Landing Gear

Flight Control Surfaces

Turbojet Engine

Figure (15), describes the turbojet engine.

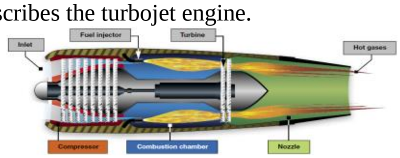

Figure (15) Turbojet Engine

Airframe Systems

Airplanes are extremely complex products comprised of many subsystems, components and parts.

Organization Structure

Organization structure explained in figure (16).

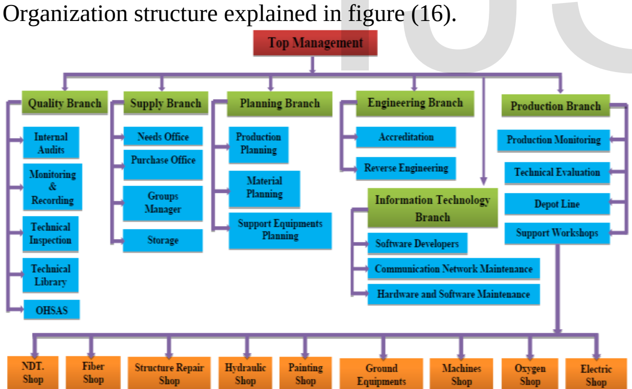

Figure (16) the Organization Structure

Airplane Maintenance

Maintenance of an A/P is of the utmost importance for safe flight.

Airplane Maintenance Level

Figure (17), explains the three organizational maintenance levels.

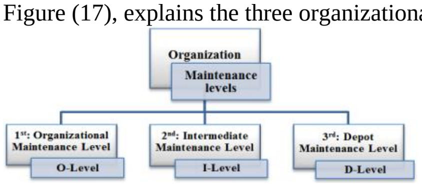

Figure (17) Organization Maintenance Levels

Organizational Maintenance Level (O-Level)

Is the day-to-day work. The O-Level activity is to maintain its A/P and equipment in a full serviceability.

Intermediate Maintenance Level (I-Level)

Supports I-Levels. Intermediate maintenance is work that is, performed in centrally located facilities at particular station.

Depot Maintenance Level (D-Level)

Supports O-Levels and I-Levels. This level will be, done according to planned phases as explained in figure (18).

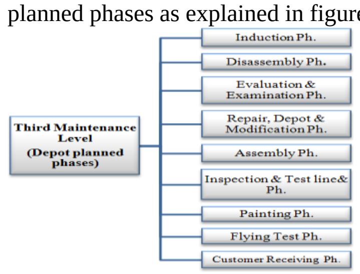

Figure (18) Organization Third Maintenance Level (D-Level)

Maintenance Procedures at A/P Str. Repair & D. Line Workshop

Figure (19) is, clarifying simply the relations between essential branches (Planning, Quality, Supply, Engineering and Production), depot line of type (F) A/P and the customers. In addition, this figure contains the third maintenance level (D-Level), takes place in the depot line of type (F) A/P, including all the scheduled phases.

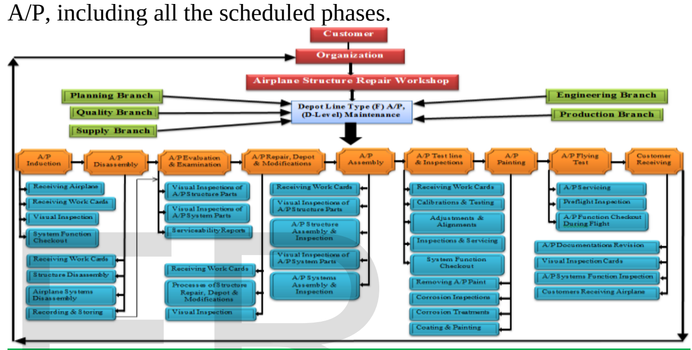

Figure (19) Third Maintenance (D-Level) Procedures

Induction Phase (Ind.)

Disassembly Phase (Disass.)

Evaluation and Examination (E&E) Phase

Repair, Depot and Modification Phase (Mod.)

Assembly (Ass.)

Inspection & Test Line (Insp. & T. Line)

Painting

Flying Test (Flying T.)

Customer Receiving (Cust. Rec.)

Organization Development

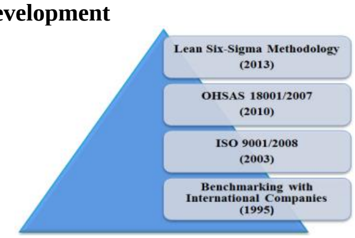

Figure (20) Organization Development

Organization is one of complex and critical systems, it is working in aviation field as a depot level for airplanes, where as it concerns to maintenance, overhaul, repair A/P service life extension and engineering modification.

"ABC Company" Data Analyses

Introduction

In this chapter, we explains the implementation of Lean Six-Sigma Methodology first three phases (Defines, Measure and Analyses) at the A/P Str. Repair & D. Line Workshop.

The Define Phase (DMAIC)

The steps of the define phase are as shown in figure (21).

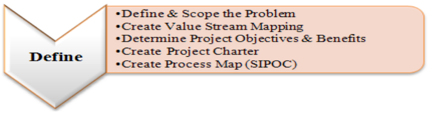

Figure (21) Steps of the Define Phase

Define and Scope the Problem

Critical to the Quality (CTQs) reflect the expressed needs of the customers, it is what the customer really wants from the process.

Identifying the Customers

Two types of customers, external and internal customers as explained in figure (22).

Figure (22) Types of Customers for A/P Str. Repair & D. Line Workshop

External Customer's (CTQs)

Customers surveys figure (23) has been, established were, sent to the airlines companies later the surveys has been, received to identify the essential customers (CTQs).

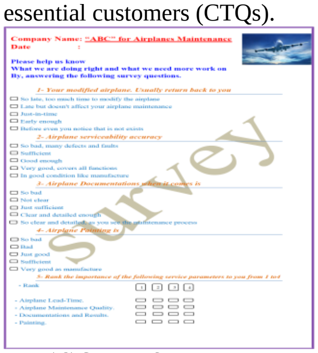

Figure (23) Customers Survey

Table (8) The Send/Receive information for Customers Survey

Surveys	Sent	Delivered	Received	Rejected	Accepted
Count	20	20	20	0	20

This survey studies two questions. The first question is how customers think about the provided maintenance service for their own airplanes in four issues, Lead (Cycle) Time, A/P Quality, documentation details, and A/P painting. The second question is what the most important parameter to the customers is. Customers' responses for the first four questions as explained in table (9) and figure (24).

Table (9) Customers Response for the First Four Questions

No. of Companies	Questions			
	1st question	2nd question	3rd question	4th question
1	1	2	3	4
2	2	3	3	4
3	2	4	4	4
4	1	3	4	4
5	2	3	3	4
6	1	4	4	3
7	3	3	3	4
8	1	4	3	3
9	2	2	4	4
10	1	4	4	4
11	1	3	3	4
12	2	3	4	4
13	1	4	4	4
14	2	3	3	4
15	1	4	4	4
16	2	3	4	4
17	3	4	4	4
18	3	4	3	4
19	1	2	4	4
20	2	3	3	4
RESULTS				
TOTAL	34	65	71	78
AVERAGE	34/20 = 1.7	65/20 = 3.25	71/20 = 3.55	78/20 = 3.9

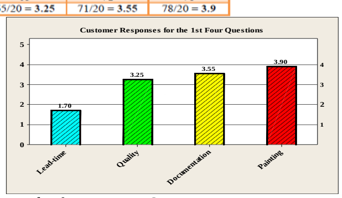

Figure (24) Customer Responses for the First Four Questions

The average results has been, divided into 5 equals regions to identify what the accurate answer is, for each individual question as explained in table (10).

Table (10) Average Regions

Average	Indication Result
1 ≤ score ≤ 1.8	1
1.8 < score ≤ 2.6	2
2.6 < score ≤ 3.4	3
3.4 < score ≤ 4.2	4
4.2 < score ≤ 5	5

The result of the first four questions is as explained in table (11).

Table (11) First Question Results for Customers Survey

Item	Indication	Result
Airplane Lead (Cycle) Time	1.70	So late, too much time to modify the airplane
Airplane Quality	3.25	Good enough
Airplane Documentation	3.55	Clear and detailed enough
Airplane Painting	3.90	Sufficient

From the above table (11), it is clear that, Lead-Time is the most (CTQs). Analyzing the responses to the (2nd question) as explained in table (12) and figure (25) and gather the both survey findings in a Quality function deployment (QFD) table.

Table (12) Customers Response for the Fifth Question

No. of Companies	Classification of Customer Importance			
	Downtime	Quality	Reporting	Painting
1	1	2	3	4
2	2	1	3	4
3	2	1	3	4
4	1	2	3	4
5	1	2	3	4
6	2	1	3	4
7	2	1	3	4
8	2	1	4	3
9	1	2	4	3
10	2	1	3	4
11	1	2	3	4
12	2	1	3	4
13	1	2	4	3
14	2	1	3	3
15	2	1	4	3
16	2	1	4	3
17	3	1	4	2
18	2	1	3	4
19	2	1	3	4
20	2	1	3	4
RESULTS				
TOTAL	35	26	66	72
AVERAGE	35/20 Company = 1.75	26/20 Company = 1.3	66/20 Company = 3.3	72/20 Company = 3.6

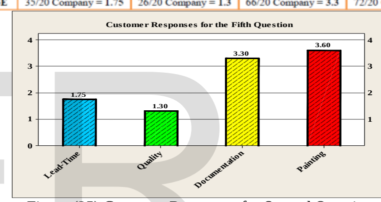

Figure (25) Customer Responses for Second Question

The most important to the customer is as explained in table (13).

Table (13) Survey's Second Question's Result

Item	Indication	Importance Rank
A/P Maintenance Quality	1.3	1st Customer requirement
A/P Maintenance Lead-Time	1.75	2nd Customer requirement
A/P Documentation	3.3	3rd Customer requirement
A/P Painting	3.6	4th Customer requirement

Internal Customers' (CTQs)

Internal customers seeks for minimize A/P maintenance time, which lead to lowering the cost of maintenance process. Table (14) shows the definitions of (CTQs).

Table (14) Internal Customer's CTQs

CTQ	Definition
Reduce Maintenance Lead-Time	Reduce the time spent during A/P maintenance process, which starts at sending A/P to the A/P Str. Repair and D. Line Workshop and finished when receiving airplanes by the customers
Reduce Airplanes Maintenance Cost	Reducing the A/P maintenance service cost especially in repair, depot and Modification phase by eliminating the non-conformances
Simplifications of Company's Management System Documentations and Airplane's Working Documents	Reducing the long time spent in documenting the A/P maintenance processes through the scheduled phases in addition, reducing the long time spent in dealing with the A/P working documents

Quality Function Deployment (QFD)

(QFD) is a "method to transform user demands into design quality shown in table (15).

Table (15) Quality Function Deployment (QFD)

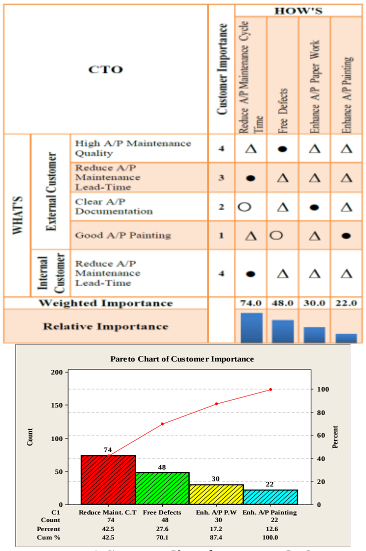

Figure (26) Pareto Chart for Process CTQs

As explained by the matrix table (15) and the Pareto chart figure (26), reducing the A/P maintenance and overhaul process (Cycle Time) is the most important (CTQs).

Airplanes Maintenance and Overhaul Process Flow Chart

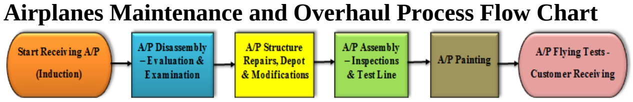

Figure (27) General Process Flow Chart for A/P Maint. and Overhaul Process

A detailed A/P maintenance and overhaul process flow chart has been, developed as explained in figure (28) in order to, develop process drill down tree.

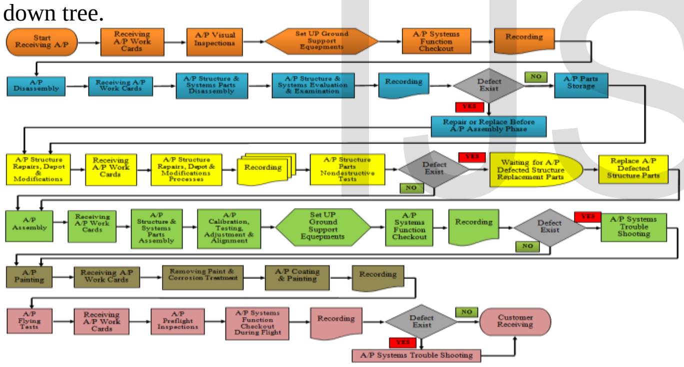
Figure (28) Detailed Process Flow Chart for A/P maint. and overhaul Process

The A/P maintenance and overhaul processes start at receiving (induction) A/P, passes through nine phases.

Induction Phase (Ind.)

Disassembly (Disass.) - Evaluation and Examination (E&E) Phase

Modification Phase (Mod)

Assembly (Ass) - Inspections and Test Line (Insp. & T. Line) Phase

Painting Phase

Flying Test (Flying T.) – Customer Receiving (Cust. Rec.) Phase

Process Drill down Tree

As explained in Figure (29)

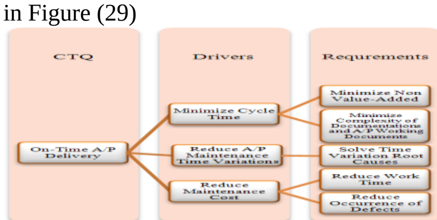

Figure (29) Process CTQs Flow Chart

Airplane Maintenance and Overhaul Process Value Stream Mapping (VSM)

The high-level current-state value stream map explained in figure (30), includes all the A/P maintenance phases. The time taken to Modify the A/P in the Modification phase is (945) hour and the value-added cycle time is (613.5) hour. A/P maintenance and overhaul detailed process flow chart figure (28), it is clear that, the Modification phase has, a high non value-added cycle time (322.5 hrs.) represented in numerous technical documentations and A/P working documents (Lead-Time).

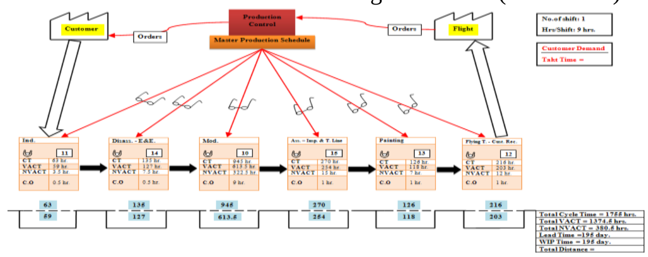
Figure (30) Current-State VSM for A/P Maint. and Overhaul Process

Project Charter

Problem Statement

The problem is, classified as long cycle time and variation for A/P maintenance and overhaul process. For the internal customer, the problem is high A/P maintenance and overhaul process cycle time and cost. For this reason, we apply Lean Six-Sigma Methodology integrated with (I.T) to improve the processes cycle time (Lead-Time), minimize defects and variation time from (195) working days to (165) working days, which reduce A/P maintenance cost.

Business Case

The management wants to improve A/P maintenance process cycle time, variation and minimize defects.

Goal Statement

The goal is to significantly reduce the non-value-added and minimize defects in addition, the increase in process Sigma-Level from 1.08 (σ) to 3.5 (σ).

Project Scope

The team will mainly focus on the A/P maintenance and overhaul process at the A/P Str. Repair & D. Line Workshop, as explained in figure (31).

Figure (31) Process Flow Diagram

Project Scope Excludes

Troubles and issues at A/P Str. Repair & D. Line Workshop has been, excluded.

Objective of This Project

The major targets for this project are A/P maintenance and overhaul process Lead-Time (non value-added) and rework time (non-conformances) reduction, occurrence of mistakes (defects) reduction, simplifying of numerous technical documentations and simplifying of the A/P working documents by increasing process Sigma from 1.08 (σ) to 3.5 (σ).

Team Selection

Table (16) Project Team

Project Name: Appling Lean Six-Sigma integrated with (I.T) at Airplanes Structure Repair and Depot Line Workshop.	Description	
Sponsoring Organization: "ABC Company"		
Project Sponsor: Eng. Mohamed Mahmoud		
Project Officer:	Name : Sherief Abo El-Naga Office Location : At Airplanes Structure Repair and Depot Line Workshop	
Team Member Name:	Job Description:	
Mohamed Labib	Production Engineer: Quality Manager, responsible for follow up of all quality activities in the workshop.	
Ahmed Foaad	Production Engineer: Planning & Scheduling Manager, responsible for follow up of all equipment and parts delivered to the workshop, planning and scheduling for all the maintenance and overhaul phases.	
Tarek Ahmed	Maintenance Engineer: Airplanes Flying Tests Manager, responsible for doing all airplanes induction, inspections, test line, painting and flying tests.	
Ibrahim Mohamed	Maintenance Engineer: Maintenance Manager, responsible for doing all airplanes maintenance and overhaul processes (airplanes modifications).	
Islam Reda	Maintenance Engineer: Maintenance Manager, responsible for tracking all assembly and disassembly procedures and directing craftsmen.	
Data Charted: 31-12-2010	Project Started Date: 1-1-2011	Target Completion Date: 1-6-2013

Project Plan

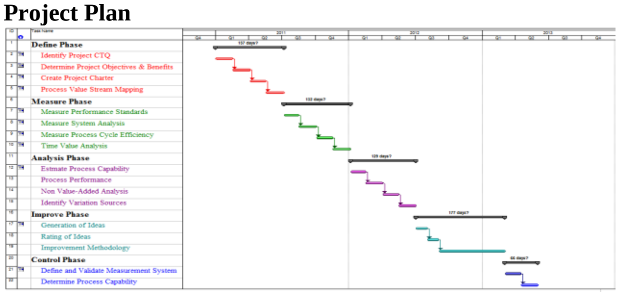

Figure (32) Project Plan

Table (17) Project Charter

Project Name:	Appling Lean Six-Sigma Integrated with (I.T) at Airplanes Structure Repair and Depot Line Workshop
Date (Last Revision):	
Prepared By:	Sherief Ahmed Abo El-Naga
Approved By:	Prof. Dr. Eng. / Abd El-Hakim El-Menhawy & Dr. Eng. / Ahmed Hossain
Business Case:	**Opportunity Statement (High Level Problem Statement):**
The management wants to improve A/P maintenance process cycle time, variation and minimize defects because A/P Str. Repair & D. Line Workshop has several complaints from the customer due to cycle time variation and the delay in delivering the airplanes back to the customers, this variation leads to customer dissatisfaction and decrease the company revenue.	Improving the processes cycle time (Lead-Time), minimize defects and minimize variation in time by applying Lean Six-Sigma Methodology integrated with (I.T), which reduce A/P maintenance cost, minimize variation in processes, increase company revenue and lead to customers satisfaction. **Defect Definition:** Time waste and variations.
Goal Statement: Project Scope	**Goal Statement: Project Scope**
In the aviation industry, we have to achieve perfection in the manufacture of airplanes components and providing services by reducing the cycle time of the A/P maintenance and overhaul process and make sure to minimize mistakes as much as possible to protect lives. In this research, we will resolve the time variation (delay) in the airplanes maintenance and overhaul process; the goal is to significantly reduce the non value-added and minimize defects in addition, the increase in process Sigma-Level from 1.08 (σ) to 3.5 (σ).	**Process Start Point:** The team will mainly focus on the A/P maintenance and overhaul process at the A/P Str. Repair & D. Line Workshop, which starts when the workshop receives the A/P, which required maintenance (overhaul). **Process End Point:** Ends after A/P flying tests and customer receiving.
Expected Savings/Benefits:	**In Scope:** Nine A/P maintenance stages from A/P receiving (induction), A/P disassembly, A/P E&E, A/P repair, depot and modification (overhaul), A/P assembly, A/P test line & inspection, A/P painting, A/P flying test and ends at customer receiving. **Out of Scope:** Troubles and issues at Airplanes Structure Repair and Depot Line Workshop due to change in production plan, shortage of material and production facility failure such as machine breaks down or operator absenteeism, are excluded.

Project Plan:				Team:	
Task/Phase	Start Date	End Date	Actual End	Name:	Role:
Define Phase	Sat 1/1/2011	Wed 6/7/2011	Wed 6/7/2011	Sherief Ahmed	A/P Depot Line Chief
Measure Phase	Thu 7/7/2011	Wed 4/1/2012	Wed 4/1/2012	Mohamed Labib	Quality Manager
Analyze Phase	Thu 5/1/2012	Sun 1/7/2012	Sun 1/7/2012	Ibrahim Mohamed	Maintenance Manager
Improve Phase	Mon 2/7/2012	Sat 2/3/2013	Sat 2/3/2013	Ahmed Foaad	Planning & Scheduling Manager
Control Phase	Mon 4/3/2013	Sat 1/6/2013	Sat 1/6/2013	Tarek Ahmed	Maintenance & Flying Tests Manager

Process Map

SIPOC Diagram

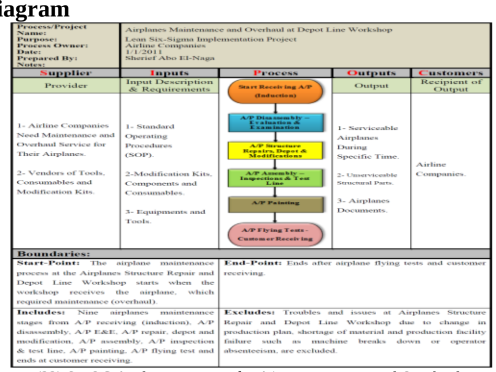

Figure (33) SIPOC Analysis Diagram for A/P Maintenance and Overhaul Process

The Measure Phase (DMAIC)

The steps of this phase are, as explained in figure (34).

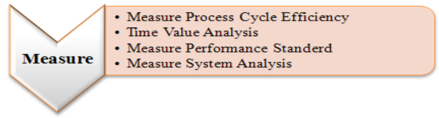

Figure (34) Steps of the Measure Phase

Process Cycle Efficiency

Table (18) and figure (35), explains process cycle efficiency for each process.

$$\text{Process Cycle Efficiency} = \frac{\text{Value-Added Cycle Time (VACT)}}{\text{Process Cycle Time (CT)}}$$

Table (18) Process Cycle Efficiency

Phases (Process)	VACT/CT	Process Cycle Efficiency %
Induction	59/63	93.65 %
Disassembly - E&E	127/135	94.07 %
Modifications	613.5/945	64.92 %
Assembly - Inspections & Test Line	254/270	94.07 %
Painting	118/126	93.65 %
Flying Test - Customer Receiving	203/216	93.98 %
Total Phases Efficiency	1374.5/1755	78.32 %

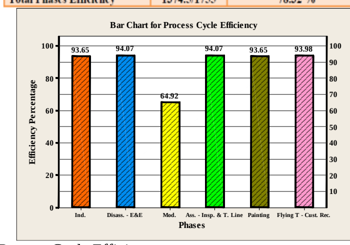

Figure (35) Bar Chart for Process Cycle Efficiency

From figure (35), it is clear that, the Modification phase has the lowest process cycle efficiency (64.92 %). Figure (36), explains the total process efficiency for the A/P maintenance and overhaul process (VA) in addition, the process deficiency (NVA).

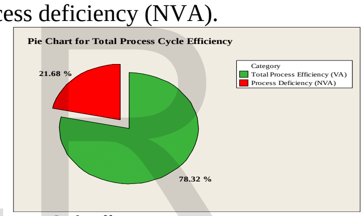

Figure (36) Pie Chart for Process Cycle Efficiency

From figure (36), it is clear that, the A/P maintenance and overhaul process has (21.68 %) non value-added. However, the non-value-added obviously identified in the following table (19) and figure (37), which shows the process, which mainly affect the total process efficiency.

Table (19) Processes NVACT Percentage

Phases (Process)	NVACT / Total NVACT	Process NVACT Percentage
Induction	4/380.5	1.06 %
Disassembly - E&E	8/380.5	2.1 %
Modifications	331.5/380.5	87.12 %
Assembly - Inspections & Test Line	16/380.5	4.2 %
Painting	8/380.5	2.1 %
Flying Test - Customer Receiving	13/380.5	3.42 %

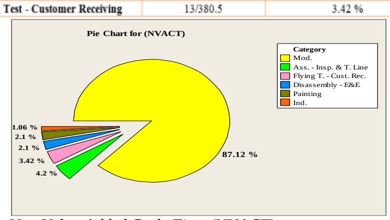

Figure (37) Pie Chart for Non Value-Added Cycle Time (NVACT)

Figure (38), shows non-value-added cycle time and identifies the process, which needs the improvement to reduce the non-value-added and increase the whole process cycle efficiency.

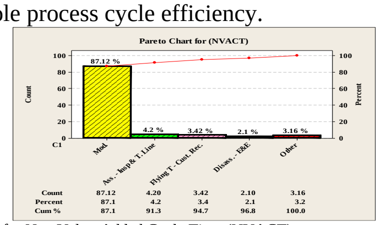

Figure (38) Pareto Chart for Non Value-Added Cycle Time (NVACT)

From figure (37) and figure (38) for the (NVACT), the Modification phase represents the highest percentage (87.12 %) of the total (NVACT), which means, the Modification phase needs improvement.

Time Value Analysis/Process Load Balance

The following table (20) and figure (39), explains the time value analysis and visually separates value-added, changeover (C.O) and non value-added time in the processes.

Table (20) Time Value Analysis

Task No.	Task Description (Phases)	NO. of Operators	VACT	C.O	NVACT	Total CT
1	Induction	11	59.0	0.5	3.5	63
2	Disassembly - E&E	14	127.0	0.5	7.5	135
3	Modifications	10	613.5	9.0	322.5	945
4	Assembly - Inspections & Test Line	15	254.0	1.0	15.0	270
5	Painting	13	118.0	1.0	7.0	126
6	Flying Test - Customer Receiving	12	203.0	1.0	12.0	216
Total Times	-	-	1374.5	13	367.5	1755

After identifying the (VACT), (C.O) and (NVACT) in table (20), the steps of the six phases and the time analysis for each process was, explained in figure (39).

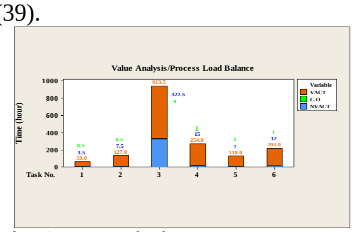

Figure (39) Time Value Analysis / Process Load Balance

Figure (39), it is clear that, phase number (3) (Modification phase) represents the highest non value-added (322.5 hrs.). Figure (40), explains the number of operators in each phase with non value-added times.

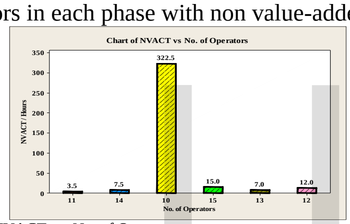

Figure (40) Bar Chart for NVACT vs. No. of Operators

In the previous figure (40), it is clear that, the Modification phase, which has the lowest number of operators (10), also has the highest non value-added time (322.5 hrs.).

Measurement Performance Standard (Target &Variation)

Specification Limits

To know the specification limit, the team collect the available historical data. All the time intervals for the nine phases for (24) A/P have been, assembled in the table (21). Table (21), Figure (41) and figure (42) was, developed in order to, determine the upper and lower specification limits.

Table (21) Historical Data for the Phases of A/P Maintenance and Overhaul Process

SER.	A / P NO.	Induc. Phase	Disass. – E&E Phase	Mod. Phase	Ass. – Insp. & Test Line Phase	Painting Phase	Flying T. – Cust. Receiving Phase	Total Time
1	A/P # 1	53	128	618	283	129	179	1390
2	A/P # 2	53	133	658	246	129	196	1415
3	A/P # 3	68	143	778	253	144	244	1630
4	A/P # 4	63	108	598	274	119	188	1350
5	A/P # 5	68	138	798	289	134	223	1650
6	A/P # 6	68	132	798	277	122	223	1620
7	A/P # 7	63	148	678	244	129	213	1475
8	A/P # 8	68	143	795	286	129	239	1660
9	A/P # 9	58	138	638	254	124	218	1430
10	A/P # 10	69	148	703	267	129	234	1550
11	A/P # 11	63	138	693	274	134	228	1530
12	A/P # 12	68	153	708	283	134	239	1585
13	A/P # 13	58	123	613	289	124	173	1380
14	A/P # 14	68	132	638	242	127	213	1420
15	A/P # 15	58	113	598	264	119	198	1350
16	A/P # 16	63	138	693	263	129	224	1510
17	A/P # 17	63	143	648	274	124	218	1470
18	A/P # 18	68	148	768	283	119	234	1620
19	A/P # 19	68	128	618	264	124	208	1410
20	A/P # 20	53	108	588	283	114	204	1350
21	A/P # 21	58	133	588	269	119	203	1370
22	A/P # 22	68	138	628	288	114	234	1470
23	A/P # 23	58	143	733	254	124	213	1525
24	A/P # 24	66	143	623	283	130	240	1485
Mean		62.958	135	674.96	270.25	125.96	216.08	1485.2
Standard Deviation		5.497	12.17	70.96	15.05	6.94	19.60	102.2

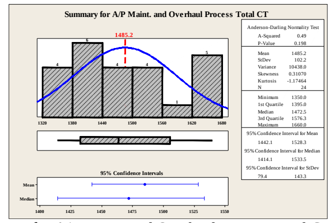

Figure (41) Descriptive Statistics for A/P Maint. and Overhaul Process Total Cycle Time

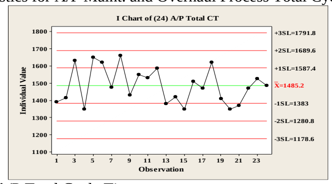

Figure (42) I-Chart for (24) A/P Total Cycle Time

Based on table (21), figure (41) and figure (42) the results was, explained in following table (22).

Table (22) Descriptive Statistics Data for A/P Maint. and Overhaul Process

Min. Time to Complete One Airplane	1350 hrs.
Max. Time to Complete One Airplane	1660 hrs.
Mean Value	1485.2 hrs.
Median Value	1472.5 hrs.
Upper Specification Limit (USL)	1660 hrs.
Lower Specification Limit (LSL)	1350 hrs.
Target	1485 hrs.
Standard Deviation	102.2 hrs.
Variance	10438
Skewness	0.31070
Kurtosis	- 1.17464

Table (22), figure (41) and figure (42) explain that, the upper specification limit (USL) equals (1660) hours. The mean value represents the target performance, which is (1485.2) hours. The lower specification limit (LSL) equals (1350) hours. The airplane that takes more than (1660) hours to be received by the customers is considered a defect.

Benchmarking

The standard time to complete the maintenance and overhaul process for one A/P is, (1450) hours without any variations.

Measurement System Analysis

Measurement Plan

- A measurement plan has been, developed and implemented in the period from 7-7-2011 to 4-1-2012 and carried out, on a six airplanes in parallel to measure the total time of nine phases of the A/P maintenance and overhaul process.
- The groups began measuring the actual phase's total time every day, starting on 8:00 AM to 5:00 PM for one shift per day, starting from induction phase and ending with customer receiving phase.

4.3.4.2. Data Collection

All the measurements, which have been, collected in the table (23).

Table (23) A/P Maint. and Overhaul Process Time per Hours for Six A/P

SER.	A / P NO.	Induc. Phase	Disass. – E&E Phase	Mod. Phase	Ass. – Insp. & Test Line Phase	Painting Phase	Flying T. – Cust. Receiving Phase	Total Time
1	A/P # 25	62	135	744	269	130	210	1550
2	A/P # 26	65	130	852	265	124	214	1650
3	A/P # 27	63	135	945	270	126	216	1755
4	A/P # 28	65	139	1015	273	129	219	1840
5	A/P # 29	60	135	1101	273	124	217	1910
6	A/P # 30	63	135	1119	270	123	220	1930

Table (23) explains four-defected A/P that takes more than (1660) hours. Therefore, we can conclude the following:

The defects per unit DPU= Defects / (Unit*opportunity) = 4/6 = 0.666667

DPMO = DPU * 1000000 = 0.66667 * 1000000 = 666666.666667

Therefore, the current process Sigma-Level according to the (DPMO) value is 1.08 (σ) and the yield is (33.55 %).

Defect: is A/P maintenance and overhaul process time, which takes more than (1660) hours to make the A/P serviceable.

The Analyze Phase (DMAIC)

The steps of the analyze phase is, as explained in figure (43).

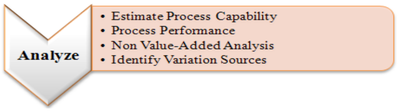

Figure (43) Steps of the Analyze Phase

Process Capability

Descriptive statistics graphical summary, I-chart for individual and Run chart for six A/P maintenance and overhaul process total time has been, charted as explained in figures (44), (45) and figure (46).

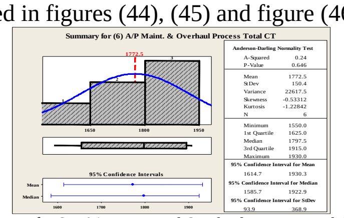

Figure (44) Descriptive Statistics for Six A/P Maint. and Overhaul Process Total CT

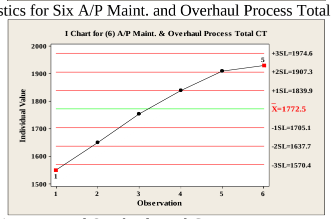

Figure (45) I-Chart for Six A/P Maint. and Overhaul Total CT

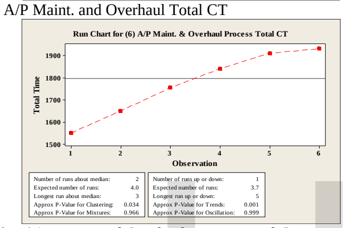

Figure (46) Run Chart for Six A/P Maint. and Overhaul Process Total CT

Table (24), explains the resulted data collected from figure (44), figure (45) and figure (46).

Table (24) Resulted Data Collected for Six A/P

Standard Deviation	150.4 hrs.
Skewness	- 0.53312
Kurtosis	- 1.22842
Median Value	1797.5 hrs.
Mean Value	1772.5 hrs.
Variance	22617.5
Approx. P- Value for Clustering	0.034 < 0.05
Approx. P- Value for Trends	0.001 < 0.05
Approx. P- Value for Mixtures	0.966 > 0.05
Approx. P- Value for Oscillations	0.999 > 0.05

Figure (44), explains that, the current process standard deviation equals to (150.4 hrs.), which considered a high value. Figure (45), explained that, there is failure passing test # (1) and test # (5). Figure (46), explains that, the approximate P-values for clustering and trends are lower than (0.05). From the previous figures, it is clear that, the data charted is not normally distributed therefore, we need a Six-Sigma project to increase the performance (minimize defects) and decrease the standard deviation (150.4 hrs.), which considered a high value. The sample mean (1772.5 hrs.) is far away from the target (1485 hrs.). The difference between the sample mean and the target (287.5 hrs.) approximately (32) working day, represents the time waste in the A/P maintenance and overhaul process. Therefore, we need a Lean project to minimize the non-value-added cycle time. Therefore, there is no need to calculate the process capability (Cpk) because the whole process is not stable. The conclusion is, we need a Lean Six-Sigma Project to increase performance (minimize defects) and decrease the non-value-added cycle time.

Airplane Maintenance and Overhaul Process Performance

All the nine phases (Compound in six phases) were, analyzed according to the data collected in table (23).

1- Graphical summary 2- Run Chart 3- I-Chart with reference lines.

Induction Phase Cycle Time Analysis

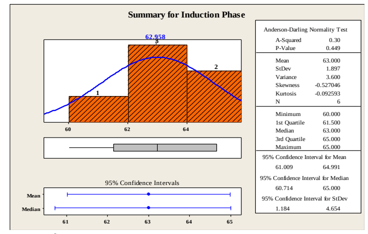

Figure (47) Descriptive Statistics for the Induction Phase CT

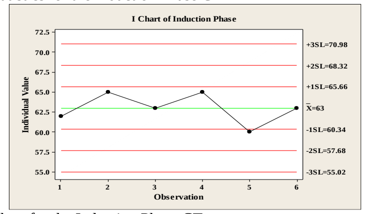

Figure (48) Individual I-Chart for the Induction Phase CT

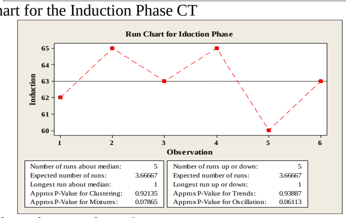

Figure (49) Run Chart for the Induction Phase CT

From the previous figures (47), (4-28) and (49) compared with table (21), we can clarify the following in table (25):

Table (25) Mean and P-Values for the Induction Phase

Current Induction Phase Mean	63.0 hrs.
Required Mean	62.958 hrs.
Approx. P- Value for Clustering	0.92135 > 0.05
Approx. P- Value for Trends	0.93887 > 0.05
Approx. P- Value for Mixtures	0.07865 > 0.05
Approx. P- Value for Oscillations	0.06113 > 0.05

The Induction phase does not need any improvements.

Disassembly - E&E Phase Cycle Time Analysis

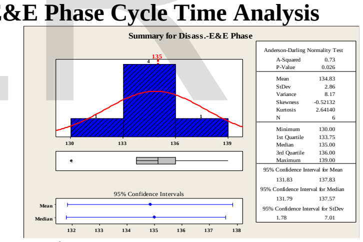

Figure (50) Descriptive Statistics for the Disass.-E&E Phase CT

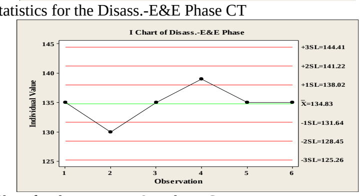

Figure (51) Individual I-Chart for the Disass.-E&E Phase CT

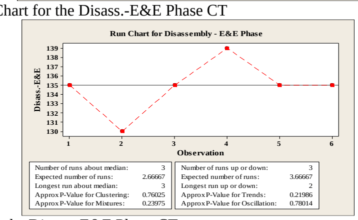

Figure (52) Run Chart for the Disass.-E&E Phase CT

From the previous figures (50), (51) and (52) compared with table (21), we can clarify the following in table (26):

Table (26) Mean and P-Values for the Disass.-E&E Phase

Current Disassembly - E&E Phase Mean	134.83 hrs.
Required Mean	135.0 hrs.
Approx. P- Value for Clustering	0.76025 > 0.05
Approx. P- Value for Trends	0.21986 > 0.05
Approx. P- Value for Mixtures	0.23975 > 0.05
Approx. P- Value for Oscillations	0.78014 > 0.05

The Disassembly - E&E phase does not need any improvements.

Modification Phase Cycle Time Analysis

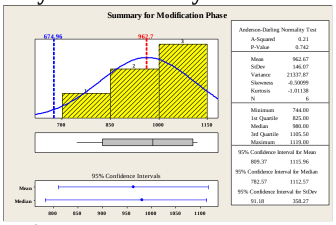

Figure (53) Descriptive Statistics for the Mod. Phase CT

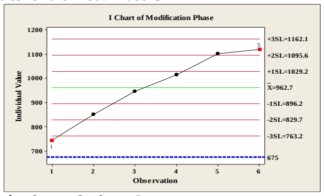

Figure (54) Individual I-Chart for the Mod. Phase CT

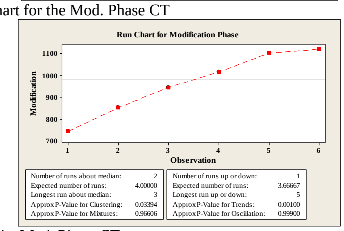

Figure (55) Run Chart for the Mod. Phase CT

From the previous figures (53), (54) and (55) compared with table (21), we can clarify the following in table (27):

Table (27) Mean and P-Values for the Mod. Phase

Current Modification Phase Mean	962.27 hrs.
Required Mean	674.96 hrs.
Approx. P- Value for Clustering	0.03394 < 0.05
Approx. P- Value for Trends	0.00100 < 0.05
Approx. P- Value for Mixtures	0.96606 > 0.05
Approx. P- Value for Oscillations	0.99900 > 0.05

The Modification phase needs improvements to decrease the current mean for the Modification phase to be (674.96 hrs.).

Assembly - Inspection & Test Line Phase Cycle Time Analysis

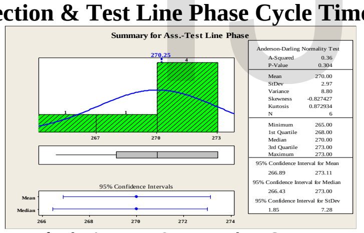

Figure (56) Descriptive Statistics for the Ass.-Insp. & T. Line Phase CT

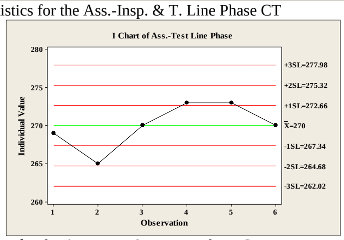

Figure (57) Individual I-Chart for the Ass.-Insp. & T. Line Phase CT

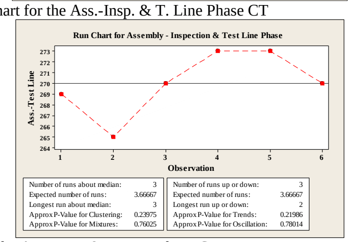

Figure (58) Run Chart for the Ass.-Insp. & T. Line Phase CT

From the previous figures (56), (57) and (58) compared with table (21) we can clarify the following in table (28):

Table (28) Mean and P-Values for the Ass.-Insp. & T. Line Phase

Current Assembly - Inspection & Test Line Phase Mean	270.0 hrs.
Required Mean	270.25 hrs.
Approx. P- Value for Clustering	0.23975 > 0.05
Approx. P- Value for Trends	0.21986 > 0.05
Approx. P- Value for Mixtures	0.76025 > 0.05
Approx. P- Value for Oscillations	0.78014 > 0.05

The Assembly - Inspection & Test Line phase does not need any improvements.

Painting Phase Cycle Time Analysis

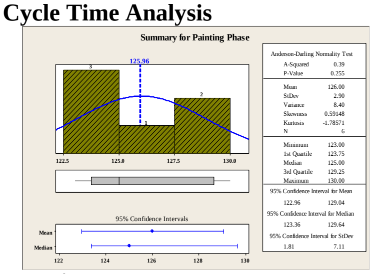

Figure (59) Descriptive Statistics for the Painting Phase CT

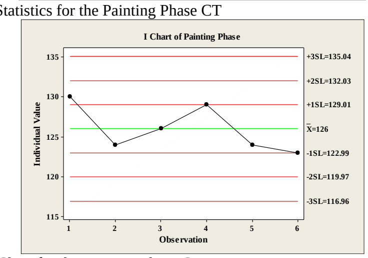

Figure (60) Individual I-Chart for the Painting Phase CT

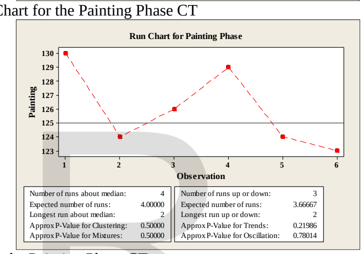

Figure (61) Run Chart for the Painting Phase CT

From the previous figures (59), (60) and (61) compared with table (21) we can clarify the following in table (29):

Table (29) Mean and P-Values for the Painting Phase

Current Painting Phase Mean	126.0 hrs.
Required Mean	125.96 hrs.
Approx. P- Value for Clustering	0.50000 > 0.05
Approx. P- Value for Trends	0.21986 > 0.05
Approx. P- Value for Mixtures	0.50000 > 0.05
Approx. P- Value for Oscillations	0.78014 > 0.05

The Painting phase does not need any improvements.

Flying Test - Customer Receiving Phase Cycle Time Analysis

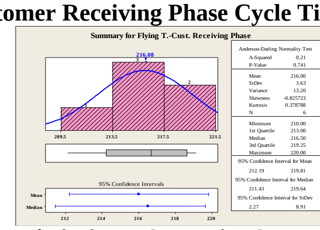

Figure (62) Descriptive Statistics for the Flying T.-Cus. Rec. Phase CT

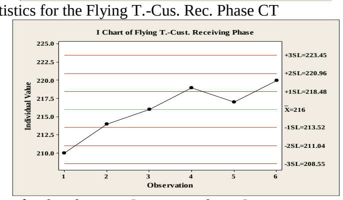

Figure (63) Individual I-Chart for the Flying T-Cust. Rec. Phase CT

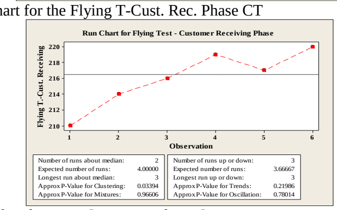

Figure (64) Run Chart for the Flying T.-Cust. Rec. Phase CT

From the previous figures (62), (63) and (64) compared with table (21) we can clarify the following in table (30):

Table (30) Mean and P-Values for the Flying T.-Cust. Rec. Phase

Current Flying Test - Customer Receiving Phase Mean	216.0 hrs.
Required Mean	216.08 hrs.
Approx. P- Value for Clustering	0.03394 < 0.05
Approx. P- Value for Trends	0.21986 > 0.05
Approx. P- Value for Mixtures	0.96606 > 0.05
Approx. P- Value for Oscillations	0.78014 > 0.05

The Flying Test - Customer Receiving phase does not need any improvements.

Total Cycle Time for A/P Maint. and Overhaul Process Analysis

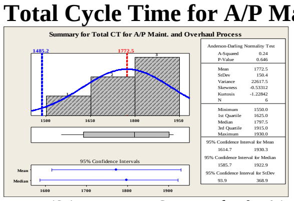

Figure (65) Descriptive Statistics for the A/P Maint. and Overhaul Process Total CT

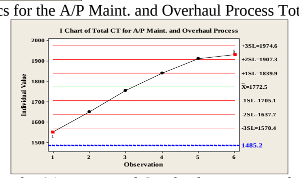

Figure (66) Individual I-Chart for the A/P Maint. and Overhaul Process Total CT

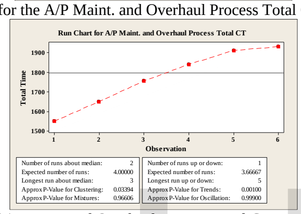

Figure (67) Run Chart for the A/P Maint. and Overhaul Process Total CT

From the previous figures (65), (66) and (67) compared with table (21) we can clarify the following in table (31):

Table (31) Mean and P-Values for the Total CT of A/P Maint. and Overhaul Process

Current Total Time of A/P Maintenance and Overhaul Process Mean	1772.5 hrs.
Required Mean	1485.2 hrs.
Approx. P- Value for Clustering	0.03394 < 0.05
Approx. P- Value for Trends	0.00100 < 0.05
Approx. P- Value for Mixtures	0.96606 > 0.05
Approx. P- Value for Oscillations	0.99900 > 0.05

The total time of A/P maintenance and overhaul process needs improvements, to decrease the current mean for the total time of A/P maintenance and overhaul process to be (1485.2 hrs.). In according to table (23), Figure (68) explains the time series plot of the six phases for six A/P, for the A/P maintenance and overhaul process.

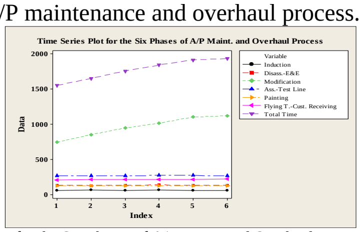

Figure (68) Time Series Plot for the Six Phases of A/P Maint. and Overhaul Process

From figure (68), it is clear that, the modification phase time is increasing and consequently, the total phases time is increasing.

Non Value-Added Analysis

We had to study the Modification phase from time value point of view as described in figure (69), which represents current-state value stream map for A/P # 27 for the A/P maintenance and overhaul process after identifying the opportunities.

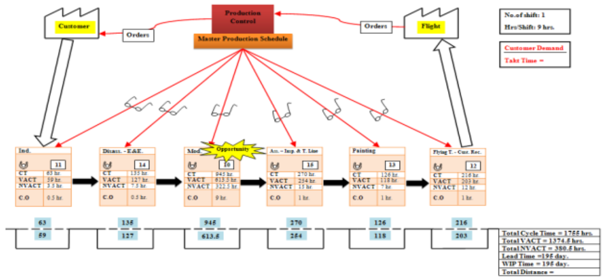

Figure (69) Current-State VSM for A/P Maint. and Overhaul Process after Identifying the Opportunities

As explained in figure (69), the Modification phase has the opportunity to be, improved and increasing the process efficiency.

Modification Phase Time Analysis

A detailed process flow chart for the Modification phase was, developed as an example, as explained in figure (70), for A/P # 27 in order to, identify the non value-added source and to have a deep look inside the Modification processes.

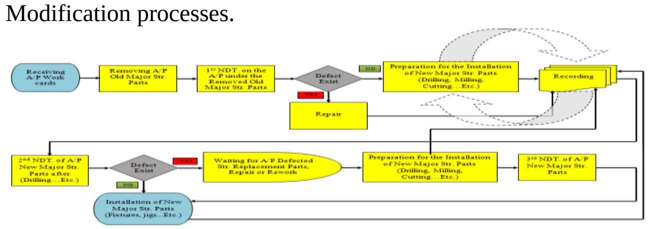

Figure (70) Detailed Process Flow Chart for the Mod. Phase

From the above figure (70), it is obvious that the time waste comes after making the second (NDT) for the new major structural parts and found those parts to be defected.

1- The waiting for A/P defected structural replacement parts to be, secured by the supply department through the vendors (**delivery time**).
2- there are another period to re-prepare those parts to be ready again for installation (**rework or replace time**). In addition, the time waste may be due to the repair and rework time (**rework or replace time**) spent in repairing the new major defected structural parts.
3- Plenty recording and reviewing of working documentations.(**A/P working documents and documentations time**).

A detailed current-state value stream map for the Modification phase was, developed for A/P # 27 as explained in figure (71), in order to, identify and analyze the Modification phase processes time and to have a deep look inside the Modification processes.

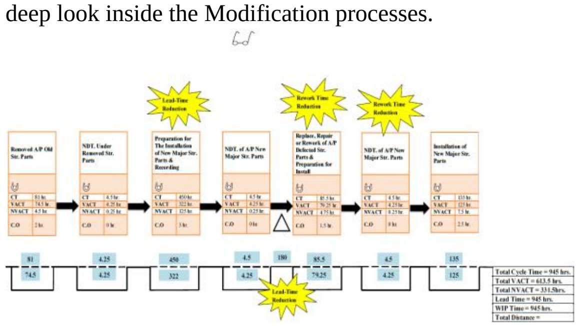

Figure (71) Current-State VSM for the Mod. Phase for A/P # 27

From figure (71), we can observe the following:

1- There are (180 hrs.), considered as a waste time, after making the second (NDT) (**delivery time or Lead-Time**).
2- There are (85.5 hrs.), considered as a waste time, for repair, rework or replace of damaged structural parts (**replace or rework time**).
3- There are (4.5 hrs.) considered, as a waste time, to make the third (NDT) on the structural replacement or reworked parts **(rework time**).
4- The process of the preparation for the installation of new major structural parts & recording, has a non value-added cycle time equal to (100 hrs.) without break time. In accordance to, figure (70), this process has a wasted time in reading, signing and reviewing plenty working documentations and dealing with airplane working docu-

ments (**A/P working documents and documentations time or Lead-Time)**.

Therefore, the total non value-added cycle time for wait, replace or rework the major structural parts and A/P documentations are (370 hrs.). Table (32), explains the summary of the VACT, NVACT, Break Time, Changeover Time and the Total Time for the Modification phase in hours.

Table (32) Summary of All Times of the Modification Phase for A/P # 27

VACT	NVACT	C.O	Break Time	Total Cycle Time
530	370	7.5	37.5	945

In addition, table (33) show the summary of all time in hours for the Modification phase in detail for A/P # 27.

Table (33) Summary of All Time for the Modification Phase in Detail for A/P # 27

SER	Task	VACT	NVACT	Break Time	C.O	CT
1	Removed A/P Old Strl. Parts	74.5	0	4.5	2	81
2	NDT. Under Removed Strl. Parts	4.25	0	0.25	0	4.5
3	Preparation for The Installation of New Major Strl. Parts & Recording (Documentation Recording)	322	100	25	3	450
4	NDT. of A/P New Major Strl. Parts	4.25	0	0.25	0	4.5
5	Waiting for defected replacement Strl. Parts (Delivery Time)	0	180	0	0	180
6	Replace, Repair or Rework of A/P Defected Strl. Parts & Preparation for Install (Rework or Replace)	0	85.5	0	0	85.5
7	NDT. of A/P New Major Strl. Parts	0	4.5	0	0	4.5
8	Installation of New Major Strl. Parts	125	0	7.5	2.5	135
	Total Cycle Time	530	370	37.5	7.5	**945**

Table (32); figure (72), explains a Pie chart for the VACT, NVACT, Break Time, Changeover Time and the Total Time for the Modification phase in hours.

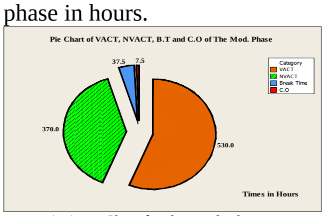

Figure (72) Pie Chart for the Mod. Phase Times

Table (33), figure (73), explains a Pareto chart for the NVACT in hours, without break time and changeover.

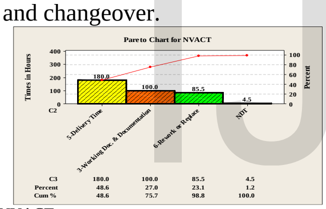

Figure (73) Pareto Chart for NVACT

From the above figure (73), we can clarify the following:

1- The highest rate in the time wasted, has come to secure the damaged structural parts from the vendors (180 hrs.).

2- Similarly, the second highest rate in the time wasted, has come from the A/P working documents and documentations reviewing and recording (100 hrs.).

3- Finally, the third and the last highest time wasted, has come from the rework or replacement of defected structural parts (90 hrs.) and making the third (NDT).

Modification Phase Defects Analysis

The team measured the numbers of defected major structural parts for A/P # 27 to get to know more on the size of the problem in addition, the prices for each item was, explained and the results were, as follows in table (4-27):

Table (34) No. of Defected Major Structural Parts for A/P # 27

Ser.	Str. Part Type	No. of Replaced Items per one A/P	No. of Defected Items for A/P # (27)	Approximate Item Price	Total Money Waste per Str. Part Type
1	Bulkhead	7	3	$ 15000	$ 45000
2	Longerons	8	4	$ 3000	$ 12000
3	Doublers	40	15	$ 900	$ 13500
4	Stringers	5	3	$ 1000	$ 3000
5	Fitting	16	8	$ 2000	$ 16000
6	Skin	15	7	$ 1500	$ 10500
	Total	**91**	**40**	-	**$ 100000**

- The above table explains the numbers of new major structural parts that should be, replaced for one A/P to complete the Modification phase tasks. In addition, the table explains the numbers of damaged major structural parts after the preparation for installation and conducting the second (NDT) also, the price for each item was also, explained. By analyzing the data in table (34), the results was as follow, in the next figure (74), figure (75) and figure (76):

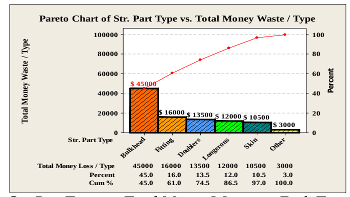

Figure (74) Pareto Chart for Str. Part Type vs. Total Money Waste per Each Type

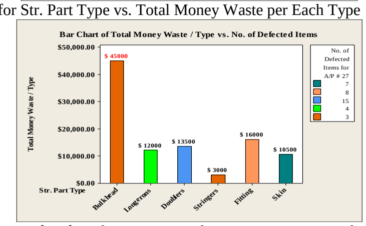

Figure (75) Bar Chart for No. of Defected Items vs. Total Money Waste per Each Type

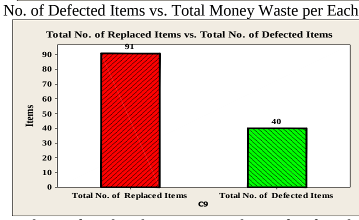

Figure (76) Bar Chart for Total No. of Replaced Items vs. Total No. of Defected Items

From the previous figures, it is clear that, the highest total money waste is ($ 45000), which considered a high value, represented in three-defected Bulkhead because it is very expensive and in most cases, the Bulkheads are irreparable. The total no. of defected Items is (40) item from (91) item per one A/P and the total money waste is ($ 100000) for all the defected major structural parts for A/P # 27, which conceded a high value.

Identify Variation Sources

Brainstorming

The team agreed that, the variation sources are, as shown in the cause and effect diagram in figure (77).

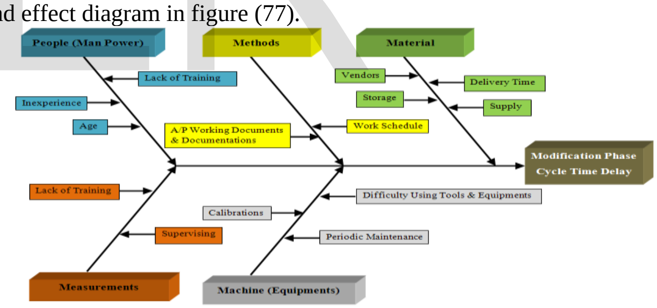

Figure (77) Cause and Effect Diagram for Variation Sources of the Modification Phase

People (Man Power)

In our case study we have (85.5 hrs.) in repairing, replacing and reworking of defected major structural parts that, there was a mistake in working on it by the technicians.

Methods

In our case study, there is NVACT due to documentations recording and estimated with (100 hrs.).

Material

We have (180 hrs.) waiting for securing defected replacements major structural parts through the vendors.

Measurements

In our case study we have (90 hrs.) in repairing, replacing and reworking of defected major structural parts.

Machine (Equipments)

In our case study we have (85.5 hrs.) in repairing, replacing and reworking of defected major structural parts that there was a mistake in working on it by the technicians.

"Developed System for Improving Performance.

The Improve Phase (DMAIC)

The main steps of the improve phase are, as explained in figure (78).

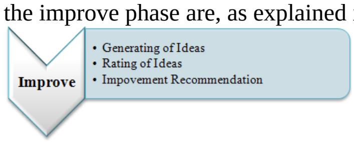

Figure (78) Steps of Improve Phase

Generation of Ideas

The alternatives are, to conduct a Simulation Based-Training (SBT) Program including all the Modification phase main tasks, sub processes, working cards, documents, tools, equipments, simulation movies, photos, drawings, A/P working documents (technical manuals) and all the information needed to complete the work, the (SBT) Program will be, used as an advanced method for training and working on the airplanes. The (SBT) Program will be, used in order to, overcome the time wasted in the A/P Mod. Phase process through, increasing the technician's level of training, transfer the work experience from the expert technicians to the trainees (increase the trainee's experience), change the working method on the airplanes, simplifying the documentations of the Modification phase processes and the of A/P working documents (technical manuals). The vital factors, are explained in figure (79).

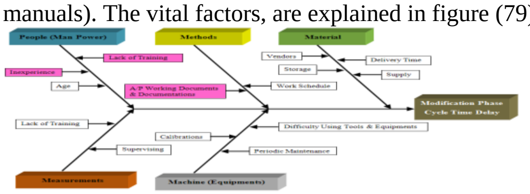

Figure (79) Generation of Ideas

A design of experiments (DOE) with two levels, full factorial design has been, performed to test the significance of the suggested vital factors and the interaction between them as explained in table (35).

Table (35) DOE Factors and Levels

Factor	Level 1 (-1)	Level 2 (1)
Technicians Experience	Inexpert	Expert
Training & Working Method	Ordinary	(SBT) Program
A/P Working Documents & Documentations	Manual	Computerized

Rating of Ideas

The First Factor (Technicians Experience)

The first level is under training technician.
The second level is expert technician.

The Second Factor (Training and Working Method)

The first level is the ordinary training and working method for technician.
The second level is a (SBT) Program.

The Third Factor (Reviewing A/P Working Documents & Documentations)

The first level is, the manual reviewing and recordings for plenty documents for all the processes of the Modification phase.
The second level is the computer reviewing, reading and recording (computerized) for plenty documents of all the Modification phase processes. Table (36) explains the experiment results.

Table (36) Full Factorial Design Experiment's Results

Run Order	Technician Experience	Training & Working Method	A/P Working Documents & Documentations	Mod. Phase Cycle Time
1	Inexpert	Ordinary	Computerized	950
2	Expert	(SBT) Program	Computerized	450
3	Inexpert	Ordinary	Manual	1000
4	Expert	Ordinary	Manual	800
5	Expert	Ordinary	Computerized	750
6	Expert	(SBT) Program	Manual	550
7	Inexpert	(SBT) Program	Computerized	500
8	Inexpert	(SBT) Program	Manual	600

Figure (80), explains a cube representation of the result and figure (81), explains the variation of the process according to the change of each factor.

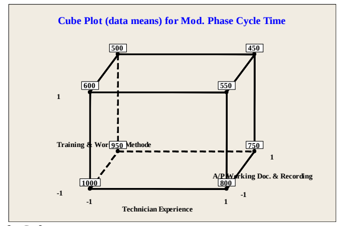

Figure (80) Experiment Result Cube Representation

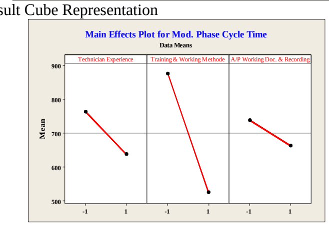

Figure (81) Experiment's Factors Variation

As explained in figures (80) and figure (81), it is clear that, the training and working method has the highest slope, it is the most affecting factor that causes the total variation in the overall process.

Improvement Methodology (Simulation Based-Training) Program

Introduction

Simulation-Based Training (SBT), designing of customized Simulation-Based Training Program (SBT) and implementing the (SBT) Program on the Modification phase.

Meaning of Airplane Structural Training

- The aviation mechanic plays a vital part in the air transportation industry.

The Organization Method of Training for A/P Structure.

The airplanes structure training provides the technician with the knowledge, skills and abilities to inspect maintain and repair A/P structures. As explained in figure (82).

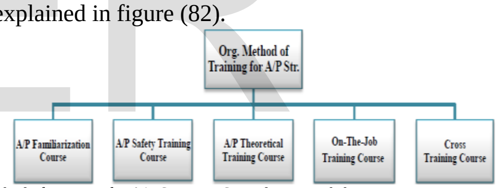

Figure (82) Method of Training for A/P Structure Specialty at Workshop

Human-Computer Interface (HCI)

Human-Computer Interface (HCI) is the means of communication between a human user and a computer system, referring in particular to the use of input/output devices with supporting software.

Using Tablet PCs in Learning

A Tablet PCs is a wireless, portable personal computer with a touch screen interface, as explained in figure (83).

Figure (83) Tablet PCs

Simulation-Based Training (SBT)

Simulation is, used to train many professionals including pilots, military personnel, business managers, and health care professionals, and is an effective active-learning technique that encourages the application of knowledge and skills in real-world scenarios.

Designing of Customized Simulation-Based Training (SBT) Program

Basic Elements of Computer-Based Information System (CBIS)
Ralph Stair and George Reynolds define a Computer-Based Information System (CBIS) as a "single set of hardware, software, databases, telecommunications, people, and procedures configured to collect, manipulate, store, and process data into information, as explained in figure (84).

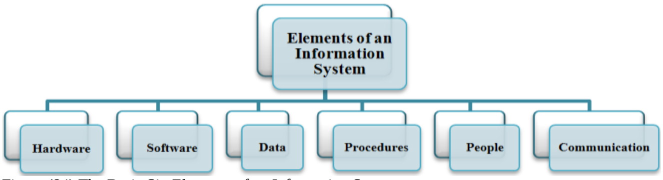

Figure (84) The Basic Six Elements of an Information System

The definition and meaning of each element of Information System (IS) is, explained in table (37). The system of the customized Simulation-Based Training (SBT) Program will be, created, taking into consideration the adaptation of the (SBT) program according to the improving requirement and capabilities of the company.

Table (37) Information System Elements Meaning and Definitions

Ser.	(IS) Elements	Definition
1	Hardware	Is the most obvious part of a (CBIS). Hardware refers to the computers themselves, along with any and all peripherals, including servers, routers, monitors, printers and storage devices. A (CBIS) may use a single computer or thousands
2	Software	Without software, the hardware wouldn't be very useful. Software, the second element of a (CBIS), is what tells the hardware how to function. It gathers, organizes and manipulates data and carries out instructions. Everything you do using a computer is done by the software
3	Data	Data, or information, is the third element of a (CBIS). Just as hardware cannot function without software, software cannot function without data. This is the information part of an information system, and whether that is statistical data, sets of instructions, lists of names or even graphics and animations, it is all key to a (CBIS)
4	Procedures	It is commonly said that "procedures are to people what software is to hardware." The fourth element of (CBIS), procedures are the rules, descriptions and instructions for how things are done. In (CBIS), procedures are frequently covered in instruction or user manuals that describe how to use the hardware, software and data
5	People	People are the most often overlooked and most important part of a (CBIS). It is people who design and operate the software, input the data, build the hardware and keep it running, write the procedures and it is ultimately people who determine the success or failure of a (CBIS)
6	Communication	Communication is left out of some lists of (CBIS) elements, but for a (CBIS) that involves more than one piece of hardware to function, communication or connectivity is a necessity. This is, in part, because parts of it are covered under hardware. The components that allow one computer to communicate with another are hardware and are controlled by software. If communication between people is included in this element, though, it is an important element

Hardware Selection
The hardware that will be, used to run the (SBT) Program is a Tablet PCs as explained in table (38).

Table (38) Tablet PCs Specifications

Tablet PCs	Tablet PC Specifications
	1- Tough filed Tablet PC 2- Water, drop and dust proof 3- Android 4.1 professional operating system 4- (3) GHz Quad core processor 5- (2) MB System ram 6- (10) Inch screen 7- Built in Wi-Fi 8- (64) GB Storage memory

Software Design
The software that will be, used to design the (SBT) Program is (ANDROID). The management assigned the information technology (I.T) Branch to develop and design the required application we used the Waterfall Methodology for the software development process. As explained in figure (85).

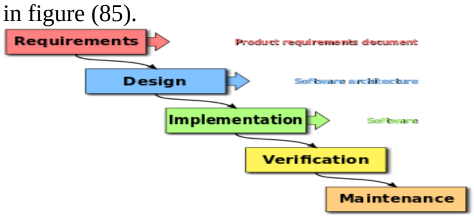

Figure (85) Waterfall Methodology

Data
The types of data that will be, incorporated in the (SBT) Program is explained in table (39).

Table (39) Types of Data Supplied to the (I.T) Branch

Ser.	Types of Data	Description
1	Mod. Phase Processes	All the technical processes accomplished in the Mod. phase including the main tasks and sub processes from the main tasks, written in word document format using Microsoft Office Program
2	Technical Manuals	All the technical manuals used and aids in accomplishment of the Mod. phase processes, in the form of Portable Document Format (PDF)
3	Videos and Photos	All the videos and photos have been taken, using a camera to the expert technician while doing the Mod. phase processes. Those videos and photos including a step by step to execute each process from the start point to the end of the process in addition, the tools, equipments, consumables, hardware, personal protection equipments and drawings are also included in the form of photos and videos

Procedures
The (I.T) software designer established a user manual for the (SBT) Program that, describe how to use the hardware, software and data including all the instructions necessary to use the (SBT) Program.

People
People are the (I.T) team who, design and operate the software, input the data, maintain the hardware and keep it running.

Communication
No need for communications because the Tablet PCs will not be, connected to each other or to a server.

Implementing the (SBT) Program on the Modification Phase
In order to, explain how the (SBT) Program function, we will take an example for one main task and the used screens for the main tasks and sub processes of the Modification phase will be, explained it in details.

Simulation-Based Training (SBT) Program Description
1- The (SBT) Program is, a program considered as an application to operate on a Tablet PCs by touching the screen and loaded with the Mod. Phase main tasks.
2- The (SBT) Program includes the sub-processes (Working Cards) from the main tasks of the Mod. Phase, each one of the sub-processes includes a numbers of operations that should be, done to complete the sub-processes consequently, completing the main tasks.
3- Each operation of the sub-processes (Working Cards) includes a step-by-step operation text and the necessary information and data needed for accomplishment of a certain task and considered helpful for the technicians to eliminate non value-added and occurrences of non-conformances (defects). Figure (86), explains the form of data and information incorporated in the (SBT) Program.

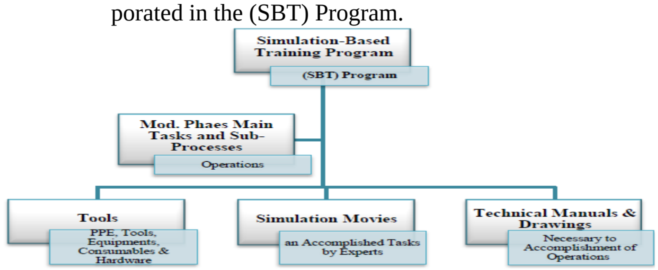

Figure (86) (SBT) Data and Information Included in the (SBT) Program

4- Tools Icon includes, all the PPE, tools, equipments, consumables and hardware assigned for and needed to complete a certain operation were, collected and pictured using a certain camera by Engineers and inserted in the (SBT) Program in the form of photos.
5- Simulation Movies Icon includes, those movies has been, taken for the expert technicians using a certain video camera while doing the same tasks and reviewed, edited and revised by the Engineering Branch.
6- Technical Manuals and Drawing Folder includes, those Technical Manuals and Drawing assigned for and needed to complete a certain operation were, collected by the Engineers in the form of (PDF) format and incorporated in the Tablet PCs in a certain folder in addition, the operations in the (SBT) Program contains the Technical Manuals name and Drawing numbers.

7- End of Operation Check Box, each operation of the sub-processes has a check box and by touching that box by the technicians, a correct mark will appear indicating the accomplishment of this operation.

Process Flow Chart for the (SBT) Program

The next figure (87), explains the process flow-chart for the (SBT) Program.

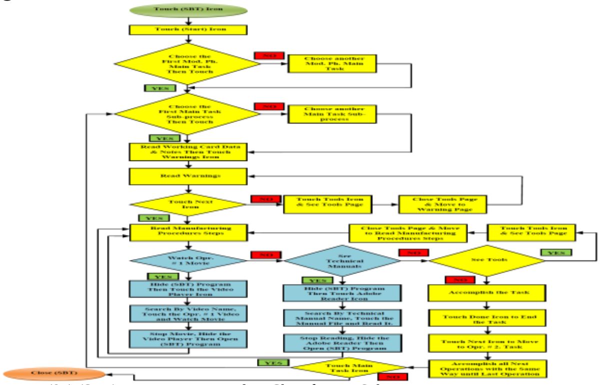

Figure (87) (SBT) Program Process Flow Chart for one Sub-Process

(SBT) Program Icon

The next figure (88), explains the shape of the (SBT) Program Icon on the screen of the Tablet PCs.

Figure (88) (SBT) Program Icon

(SBT) Program Start Page

The (SBT) Program will start, showing up the first page.

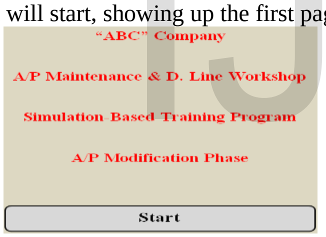

Figure (89) (SBT) Program Start Page

(SBT) Program Modification Phase Main Tasks

The (SBT) Program will start, showing up the Mod. Phase main tasks page.

Figure (90) (SBT) Program Mod. Phase Main Tasks Page

(SBT) Program Modification Phase Sub Processes

As an example of Mod. Phase (Main Task) choosing, the next page will be, displayed showing up the main task (Structure Skin Repair & Nut Installation) sub processes page. By touching, (15N1536-01M) Icon, as an example of (Sub-Process) choosing, the next page will show up.

Figure (91) Sub-Processes of the Main Task

(SBT) Program Sub Processes Operations (Working Card)

After touching (15N1536-01M) Icon, as an example of (Sub-Process) choosing, the next page will be, displayed showing up the sub-process (15N1536-01M) operations page.

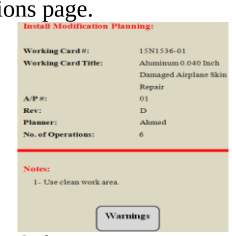

Figure (92) First Page of the Working Card

By touching the (Warnings) Icon, the next page will show up.

(SBT) Program Sub Processes Operations (Warnings and Tools)

The next page will be, displayed showing up the warnings and tools page.

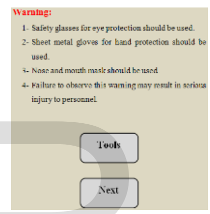

Figure (93) Warnings and Tools Page

By touching the (Next) Icon, the next page will show up.

Figure (94) PPE, Tools, Equipments, Consumables and Hardware Page

Figure (95) PPE, Tools, Equipments, Consumables and Hardware Page

Figure (96) PPE, Tools, Equipments, Consumables and Hardware Page

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Figure (97) PPE, Tools, Equipments, Consumables and Hardware Page

(SBT) Program Sub Processes Operations (Working Card)

The next page will be displayed, showing up the manufacturing procedures steps for Opr. # 1.

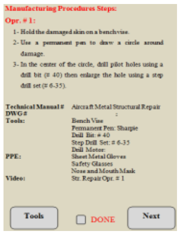


Figure (98) Working Card First Page Display (Opr. # 1)

Manufacturing procedures steps:

- The technicians' first step is to read the step-by-step text to follow the instructions.
    - As explained in figure (94), figure (95), figure (96) and figure (97) containing all the requirements needed to accomplish the task.
- The technicians' second step is to start execute the step-by-step operation, if the technicians want to watch how the Opr. # 1 is, done assuming that, he did not do the operation before, he is unsure of doing it right or he wants to know the place of the operation on the A/P, the technicians hide the (SBT) Program application and start touch the (Video Player) Icon on the screen of the Tablet PCs with a simple touch, as explained in figure (99).


Figure (99) The Video Player Icon.

- The technicians start search for the required movie by the title of the movie which has been, written in the working card first page, as explained in figure (98), with a simple touch on the required movie file it will be, opened and the technicians can watch a full movie of the Opr. # 1, showing the technicians how the work is, done and picking up the required information to complete the Opr. # 1, as explained in figure (100). Those movies has been, taken for the expert technicians using a certain video camera while doing the same tasks and reviewed, edited and revised by the Engineering Branch.

Figure (100) Screen Shoot for Opr. # 1 Movie

- The technicians' third step is to open the technical manuals, if the technicians want to review the technical manuals for executing Opr. # 1 (in our case example it will be Aircraft Metal Structure Repair Book), start touch the (Adobe Reader) Icon on the screen of the Tablet PCs, as explained in figure (101) with a simple touch.

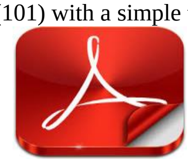


Figure (101) Adobe Reader Icon

- After opening the adobe reader, the technician will find a folder named (Documents), this (Documents) folder containing all the technical manuals or drawings files in the form of (PDF) format that are, needed for accomplishing tasks related to all the operations included in the (SBT) Program. As explained in figure (98), with a simple touch on the required (PDF) file it will be, opened and the technicians can read, review it and picking up the required information to complete the Opr. # 1, as explained in figure (102).

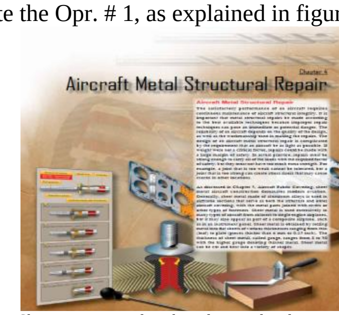


Figure (102) Screen Shoot For Required Technical Manuals File

- The technicians' fourth step is, ending the Opr. # 1 and move to the next Opr. # 2, after the technician accomplished Opr. # 1 on the A/P, he touch the (Check Box) Icon, a correct mark will appear inside the icon which, considered an evidence of ending the operation, as explained in figure (103) and if the he wants to move to Opr. # 2, he simply touches the (Next) Icon and the Opr. # 2 page will appear and start the procedures again and so on, as explained in figure (104) and figure (105).

Figure (103) A Correct Mark Appears, Showing the End of the Operation

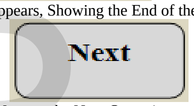


Figure (104) The Next Icon to Move to the Next Operation

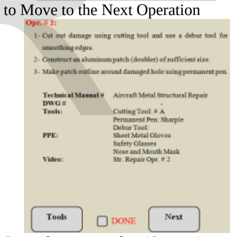


Figure (105) Working Card Second Page Display (Opr. #2)

- The fifth and final step is, ending the whole working card operations, as explained in figure (106), figure (107) and figure (108) in our case example ending the (15N1536-01M) sub-process, after the technician accomplished all operations related to the working card (15N1536-01M), he will be at Opr. # 6. Opr. # 6. page has a (Check Box) Icon, when the technician accomplish the whole working card, he simply touches the (check Box) Icon and a correct mark will appear indicating accomplishment of this working card, as explained in figure (109). Opr. # 6. has a (Main Task) Icon, simply the technician move to the Mod. Phase main tasks, as explained in figure (90) by touching this icon.

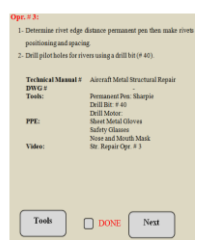


Figure (106) Working Card Opr. # 3

Figure (107) Working Card Opr. # 4

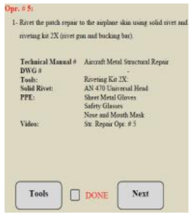


Figure (108) Working Card Opr. # 5

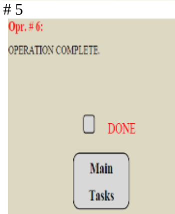


Figure (109) Working Card Last Opr. # 6

The Control Phase (DMAIC)

The main steps of the control phase are, as explained in figure (110).

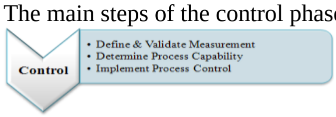


Figure (110) Steps of Control Phase

Define and Validate Measurement

Measurement Results

- A measurement time plan on a six A/P in parallel, to measure the total time of nine phases of the A/P maintenance and overhaul processes after the implementation of the (SBT) Program.

The measurement plan and results for six, A/P are, summarized in table (40).

Table (40) Control Phase Measurement Results

SER.	A / P NO.	Induc. Phase	Disass. – E&E Phase	Mod. Phase	Ass. – Insp. & Test Line Phase	Painting Phase	Flying T. – Cust. Receiving Phase	Total Time
1	A/P # 31	63	135	727	268	129	215	1537
2	A/P # 32	62	137	664	274	125	210	1472
3	A/P # 33	65	135	714	271	125	214	1524
4	A/P # 34	63	135	675	270	126	216	1485
5	A/P # 35	62	132	649	269	123	214	1449
6	A/P # 36	63	140	596	270	127	221	1417

Modification Phase Defects Measurements Results

- The team measured the numbers of defected major structural parts for A/P # 34 as an example, after the implementation of the (SBT) Program in addition, the prices for each item was, explained and the results were, as explained in table (41):

Table (41) No. of Defected Major Structural Parts for A/P # 34

Ser.	Str. Part Type	No. of Replaced Items per one A/P	No. of Defected Items for A/P # (34)	Approximate Item Price	Total Money Waste per Str. Part Type
1	Bulkhead	7	0	$ 15000	$ 0
2	Longerons	8	0	$ 3000	$ 0
3	Doublers	40	2	$ 900	$ 1800
4	Stringers	5	0	$ 1000	$ 0
5	Fitting	16	1	$ 2000	$ 2000
6	Skin	15	0	$ 1500	$ 0
Total		91	3		3800

- By analyzing the data in table (41) the results was, explained in the next figure (111):

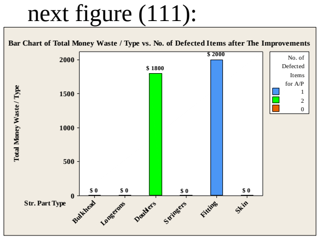


Figure (111) Bar Chart for No. of Defected Items vs. Total Money Waste per Each Type after the improvement

- From the previous figure (111), it is clear that, the highest total money waste is ($ 2000), represented in two defected Doublers.
- The total money waste is ($ 3800) for all the defected major structural parts for A/P # 34 after the improvement took place, which conceded a low value compared to the total money waste ($ 100000) for all the defected major structural parts for A/P # 27 before the improvement took place, see table (34).

Control Phase Process Capability

Using the data collected in the control phase from table (40), for A/P # 34, as explained in figure (112), figure (113) and figure (114).

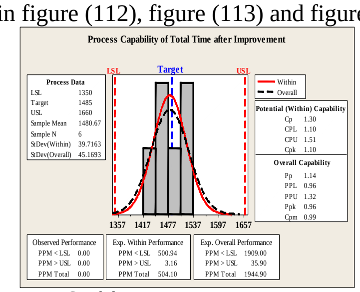


Figure (112) Control Phase Process Capability

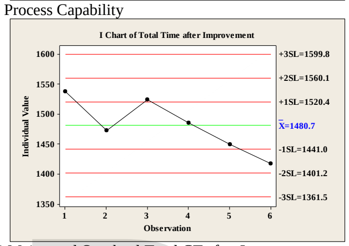


Figure (113) I-Chart forA/P Maint. and Overhaul Total CT after Improvement

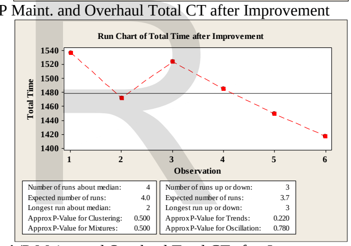


Figure (114) Run Chart for A/P Maint. and Overhaul Total CT after Improvement

we can explain the following, in table (42):

Table (42) Data Collected after Improvement

Standard Deviation	45.1693 hrs.
Cp	1.3
Cpk	1.10
Mean Value	1480.67 hrs.
Target	1485 hrs.
Approx. P- Value for Clustering	0.50 > 0.05
Approx. P- Value for Trends	0.220 > 0.05
Approx. P- Value for Mixtures	0.50 > 0.05
Approx. P- Value for Oscillations	0.780 > 0.05

1- Figure (112), the process of A/P maintenance and overhaul is stable and capable after applying the improvement methodology. In additions, the mean value for the six airplanes after improvement is lower than the desired target, which means, the target was, reached.
2- Figure (113), explains that, all the points passed all the tests and there are no points out of control.
3- Figure (114) indicates that, the data are neither clustered, mixture, oscillated nor trended.

Sigma-Level Measurement

In accordance to, the Cpk value (1.10), from figure (112) and in accordance to, the calculation of Sigma-Level using Z-Type method.
Cpk value (1.10) is an indication for Sigma-Level value (3.3) with non-conforming PPM value (966.9651). The current process Sigma-Level after the improvement is 3.3 (σ).

A/P Maintenance and Overhaul Process (VSM) after Improvement

A high-level value stream map for A/P # 34 after the improvement took place in figure (115), in addition, and high-level value stream map for A/P # 34 after the improvement took place in figure (116). From figure

(115), figure (116), figure (69) and figure (71), we can explain the following in table (43):

Table (43) Cycle Time in Hours before and after the improvement

Ser.	Process	Cycle Time before Improvement	Cycle Time after Improvement
1	Modification	945	675
2	A/P Maintenance and Overhaul	1755	1485

As explained in table (43), the Mod. Phase cycle time decreased from (945 hrs.) to (675 hrs.) after the improvement took place consequently, the total A/P maintenance and overhaul process cycle time decreased from (1755 hrs.) to (1485 hrs.) after the improvement took place.

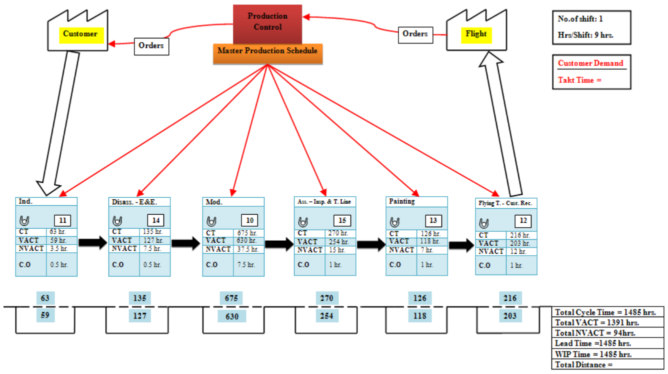


Figure (115) VSM for A/P Maint. and Overhaul Process after the Improvement

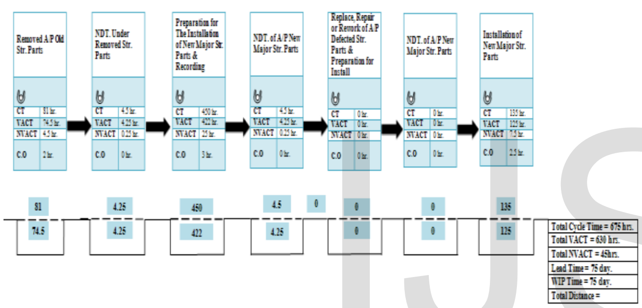


Figure (116) VSM for Mod. Phase Process after the Improvement

Implement Process Control

A Mistake Proofing (Poka-Yoke) Methodology has, been developed to perform four main tasks, as explained in table (44).

Table (44) Process Control Tasks

Process Control Tasks	
1	Accreditation of the (SBT) Program by the Engineering Branch will be-done. At the same time, the (SBT) program will be circulated to all incoming airplanes.
2	Ensuring the appropriate specifications of the Tablet PCs with the (I.T) Branch and securing the money budget with the management.
3	Providing a periodic training, one lecture per week including practical tests for the structure repair technicians that, intended to publicize the (SBT) Program in order to, minimizing errors using it, how to use it, benefits from it, how to use the Tablet PCs and the Android applications.
4	The Mod. Phase time will be-updated in the control charts after the implementation of the (SBT) Program. Then, each A/P maintenance and overhaul process, especially the Mod. Phase has to be-monitored and charted in Control chart & reviewed to ensure a controlled process.

The Mistake-Proofing Methodology will be, achieved as follows:

1- The accreditation of the (SBT) Program by the Engineering Branch will be, done as an effective tool for use in the A/P Mod. Phase instead of using the old way of working and training on the A/P.

2- Provide (60) Tablet PCs from the market, as explained in table (45):

Table (45) Company Plane for Providing the Tablet PC

Order No.	No. of Tablet PC	Delivery Order	Tablet PC Specifications
1st Order	20	1-8-2013	1- Tough filed Tablet PC 2- Water, drop and dust proof 3- Android 4.1 professional operating system 4- (3) GHz Quad core processor 5- (2) MB System ram 6- (10) Inch screen 7- Built in Wi-Fi 8- (64)GB Storage memory
2nd Order	20	1-9-2013	
3rd Order	20	1-10-2013	

3- A training for the (SBT) Program started at 31-8-2013 to 21-11-2013 as follow in figure (117),

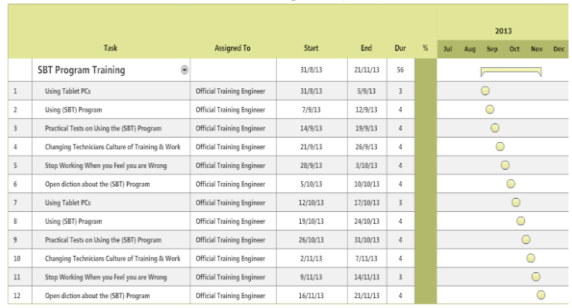


Figure (117) Three-Month Weekly Training Plan for the (SBT) Program

4- The Modification phase time will be, updated in the Control charts after the implementation of the (SBT) Program. Then, each A/P maintenance and overhaul process specially the Mod. Phase has to be, monitored and charted in Control chart after every process and take immediate corrective actions.

"Conclusions and Recommendations

Implementing Integrated Approach of Lean Six-Sigma with (I.T) at A/P Str. Repair & D. Line Workshop

- (DMAIC) was utilized, as a systematic approach, after utilizing the (DMAIC) procedure, corrective actions were taken to reduce the Lead-Time and the non-conformance (rework time) and thereby the result was to reduce the Modification phase cycle time from (945 hrs.) to (675 hrs.) consequently, the A/P maintenance and overhaul process was reduced from (1755 hrs.) to (1485 hrs.)
- Depending on the integration of the (I.T) into the improve phase of (DMAIC), the corrective action was conducting a (SBT) Program used as, an advanced method for training and working on the airplanes.
- The data explained that, there are benefits implementing Lean Six-Sigma approach integrated with (I.T) at A/P Str. Repair & D. Line Workshop and the Lean Six-Sigma Methodology integrated with (I.T) was, found to be, an effective problem solving approach.
- Implementing Lean Six-Sigma at A/P Str. Repair & D. Line Workshop must be a company-wide initiative.

A/P Str. Repair & D. Line Workshop Saving in Maintenance Time

- The A/P maintenance and overhaul process time, using the (SBT) Program is dramatically decreased, not only decreasing the non value-added but also decreasing the non-conformance (defected structural parts) simultaneously increasing the company revenue. The results of implementing (SBT) Program is, External and internal customer satisfaction.

The following charts for the Mod. Phase and total A/P maintenance and overhaul process were, explained before and after the improvement took place using the data in table (23) and table (40).

Modification Phase Cycle Time before and after the Improvement

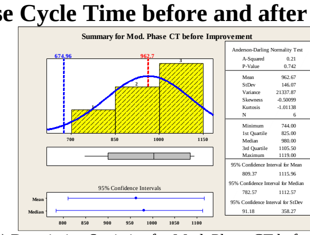


Figure (118) Descriptive Statistics for Mod. Phase CT before Improvement

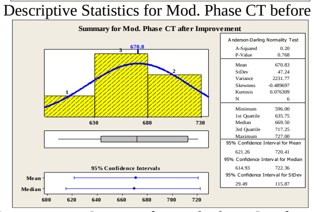


Figure (119) Descriptive Statistics for Mod. Phase CT after Improvement

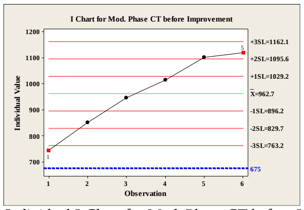


Figure (120) Individual I-Chart for Mod. Phase CT before Improvement

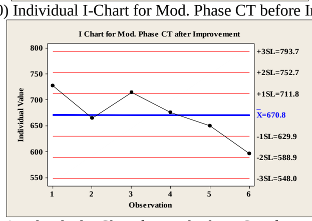


Figure (121) Individual I-Chart for Mod. Phase CT after Improvement

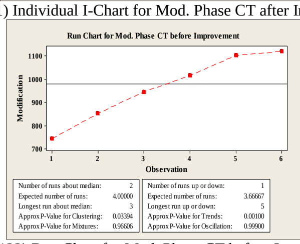


Figure (122) Run Chart for Mod. Phase CT before Improvement

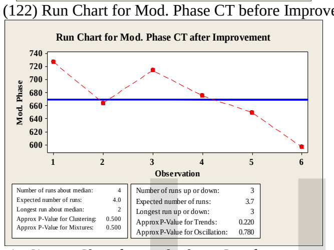


Figure (123) Run Chart for Mod. Phase CT after Improvement

A comparison between the data collected explained in table (46).

Table (46) Data Comparison before and after the Improvement for Mod. Phase

Observations	Before Improvement	After Improvement
Sample Mean	962.67 hrs.	670.83 hrs. (Target = 675 hrs.)
Standard deviation	146.07 hrs.	47.24 hrs.
Variance	21337.87	2231.77
Median	980.00 hrs.	669.50 hrs.
Control Charts Tests	Failure Test 1 and 5	Pass all Tests
Approx P Value for Clustering	0.03394< 0.05	0.500> 0.05
Approx P Value for Trends	0.00100< 0.05	0.220> 0.05
Approx P Value for Mixtures	0.96606> 0.05	0.500> 0.05
Approx P Value for Oscillations	0.99900> 0.05	0.780> 0.05

Total Cycle Time for A/P Maintenance and Overhaul Process before and after the Improvement

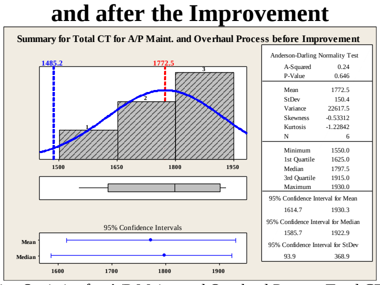


Figure (124) Descriptive Statistics for A/P Maint. and Overhaul Process Total CT before Improvement

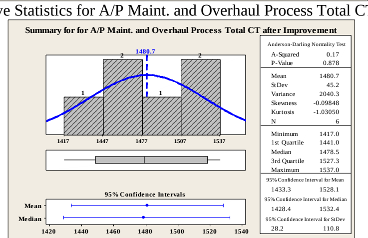


Figure (125) Descriptive Statistics for A/P Maint. and Overhaul Process Total CT after Improvement

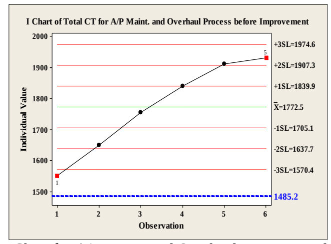


Figure (126) Individual I-Chart for A/P Maint. and Overhaul Process Total CT before Improvement

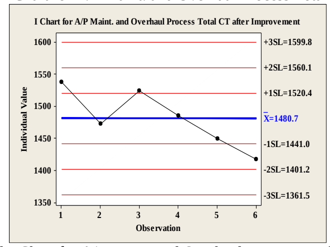


Figure (127) Individual I-Chart for A/P Maint. and Overhaul Process Total CT after Improvement

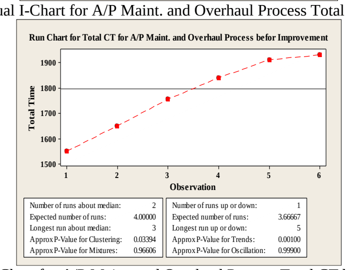


Figure (128) Run Chart for A/P Maint. and Overhaul Process Total CT before Improvement

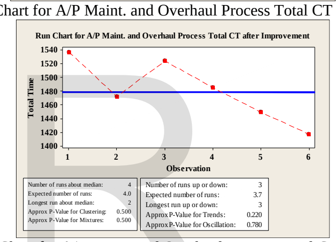
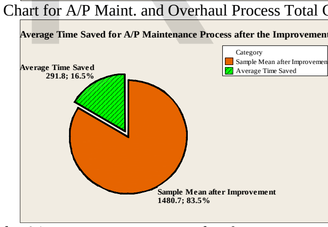


Figure (129) Run Chart for A/P Maint. and Overhaul Process Total CT after Improvement



(130) Average Time Saved for A/P Maintenance Process after the Improvement

A comparison between the values were, explained in table (47).

Table (47) Data Comparison before and after the Improvement for A/P Maint. and Overhaul Process

Observations	Before Improvement	After Improvement
Sample Mean	1772.5 hrs.	1480.7 hrs. (Target = 1485 hrs.)
Standard deviation	150.4 hrs.	45.2 hrs.
Variance	22617.5	2040.3
Median	1797.5 hrs.	1478.5 hrs.
Control Charts Tests	Failure Test 1 and 5	Pass all Tests
Approx P Value for Clustering	0.03394< 0.05	0.500> 0.05
Approx P Value for Trends	0.00100< 0.05	0.220> 0.05
Approx P Value for Mixtures	0.96606> 0.05	0.500> 0.05
Approx P Value for Oscillations	0.99900> 0.05	0.780> 0.05

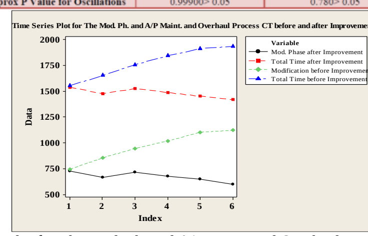


Figure (131) Time Series Plot for The Mod. Ph. and A/P Maint. and Overhaul Process CT before and after Improvement

From figure (131), the A/P maintenance and overhaul process time series line (red) and the Modification phase time series line (black) was, decreasing after the improvement took place compared to the A/P maintenance and overhaul process time series line (blue) and the Mod. Phase time series line (green) before improvement.

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Modification Phase Non-conformances before and after the Improvement

Table (48), explains the numbers of defected major structural parts for A/P # 27 before the improvement took place and for A/P # 34 after the improvement took place in addition, the total money waste before and after the improvement.

Table (48) No. of Defected Major Structural Parts for A/P # 27 and A/P # 34 before and after the improvements

Ser.	Str. Part Type	No. of Replaced Items per one A/P	Approximate Item Price	Before Improvement		After Improvement	
				No. of Defected Items for A/P # (27)	Total Money Waste per Str. Part Type	No. of Defected Items for A/P # (34)	Total Money Waste per Str. Part Type
1	Bulkhead	7	$ 15000	3	$ 45000	0	$ 0
2	Longerons	8	$ 3000	4	$ 12000	0	$ 0
3	Doublers	40	$ 900	15	$ 13500	2	$ 1800
4	Stringers	5	$ 1000	3	$ 3000	0	$ 0
5	Fitting	16	$ 2000	8	$ 16000	1	$ 2000
6	Skin	15	$ 1500	7	$ 10500	0	$ 0
Total No. of Defects				40	-	3	-
Total Money Waste				-	$ 100000	-	$ 3800

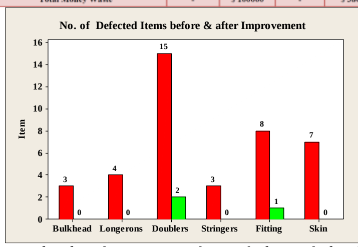

Figure (132) Bar Chart for No. of Defected Items per Each Type before and after the improvement

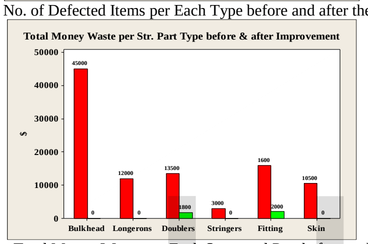

Figure (133) Bar Chart for Total Money Waste per Each Structural Part before and after the Improvements

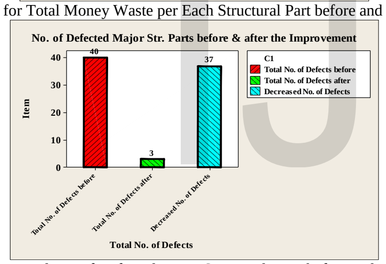

Figure (134) Bar Chart for Total No. of Defected Major Structural Parts before and after the Improvements

The total numbers of defected major structural parts after the improvement was, decreased from (40) to (3) after the implementation of the (SBT) Program, as explained in figure (134).

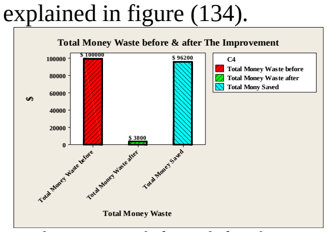

Figure (134) Bar Chart for the Total Money Waste before and after The Improvement

A/P Maintenance and Overhaul Process Flow Chart after Improvement

A detailed A/P maintenance and overhaul process flow chart, as explained in figure (135) and a detailed A/P Mod. Phase process flow chart, as explained in figure (136) has, been developed after the improvement took place.

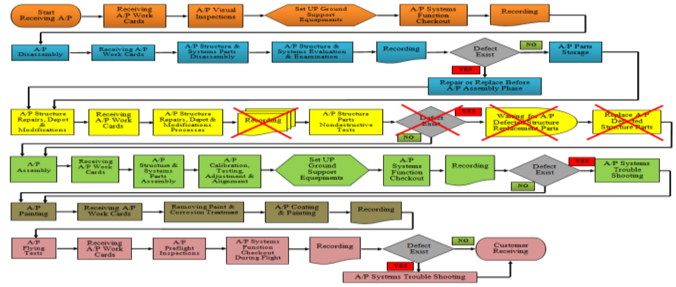
Figure (135) Detailed Process Flow Chart for A/P maint. and overhaul Process after Improvement

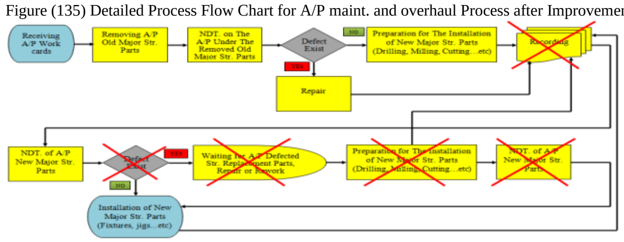
Figure (136) Detailed Process Flow Chart for the Mod. Phase after Improvement

A/P Maintenance and Overhaul Process Efficiency after the Improvement

From the previous current-state value stream map figure (30) before the improvement and the from the previous value stream map figure (115) in the control phase, after the improvement took place. We will calculate the process cycle efficiency using the values of value-added time and total cycle time in processes as explained in table (49) and figure (137).

Table (49) Increasing the Mod. Phase and A/P Maint. and Overhaul Process Efficiency

No.	Process	Before	Process Cycle Efficiency %	After	Process Cycle Efficiency %	Increasing Efficiency %
		VACT/CT		VACT/CT		
1	Modification	613.5/945	64.92 %	630/675	93.33 %	28.41 %
2	A/P Maintenance and Overhaul	1374.5/1755	78.32 %	1391/1485	93.67 %	15.35 %

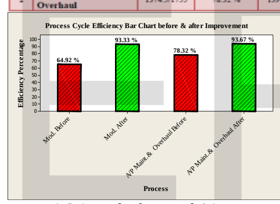

Figure (137) Mod. Phase and A/P Maint. and Overhaul Process Efficiency before and after Improvement

A/P Maintenance and Overhaul Process Saved Time after the Improvement

From figure (30) in the define phase, before the improvement and the from the previous value stream map figure (115) in the control phase. The total cycle time for the A/P maintenance and overhaul process is, explained in table (50).

Table (50) Total A/P maintenance Process before and after the improvement for A/P # 27 & A/P # 34

Ser.	Process	Cycle Time before Improvement	Cycle Time after Improvement	Saving in Maintenance Time
1	A/P Maintenance and Overhaul	1755	1485	270

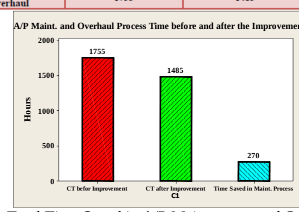

Figure (138) Total Time Saved in A/P Maintenance and Overhaul Process

Conclusions

After identifying, the roots causes of the delay in Airplanes maintenance and overhaul process time and found those causes as follow:

- Securing the damaged structural parts from the vendors
- A/P working documents and documentations reviewing and recording
- Rework or replacement of defected structural parts

The systematic use of the Lean Six-Sigma Methodology integrated with (I.T) through the paper, ensured savings in terms of money and time. Therefore, Applying Lean Six-Sigma at A/P Str. Repair & D. Line Workshop led to:

1- Increasing the Modification phase process cycle efficiency from (64.92 %) to (93.33 %), consequently the process cycle efficiency for airplanes maintenance and overhaul process increased from (78.32 %) to (93.67 %).
2- Increasing the process Sigma-Level from 1.08 (σ) to 3.3 (σ).
3- Decreasing the average standard deviation, for the A/P maintenance and overhaul process, from (150.4 hrs.), before the improvement to (45.2 hrs), after the improvement.
4- Internal customer satisfaction through, decreasing the A/P maintenance and overhaul process cycle time from (195) working days, before the improvement, to (165) working days after the improvement.
5- Internal customer (the stakeholders) satisfaction through, decreasing the A/P maintenance cost for one A/P from ($ 100000) before the improvement to ($ 3800) after the improvement which means, saving ($ 96200) by minimizing occurrence of non-conformance (defected or damaged structural parts) and variation in time (rework time).
6- Internal customer (technicians) satisfaction by computerizing the system documentations and A/P working documents and make the process easier than before through transferring the work experience by using the (SBT) Program, which is an advanced training technique used for working and training on the airplanes, to increase the technician's level of training.
7- External customer satisfaction through decreasing the airplanes maintenance and overhaul process cycle time and receiving the A/P in accurate time without long time variations…..from (195) working days before the improvement to (165) working days after the improvement

Recommendations

1- Providing a periodic training, including practical tests for the structure repair technicians that, intended to publicize the (SBT) Program to the technicians, minimizing errors using it, how to use it, benefits from it, how to use the Tablet PCs and the Android applications.
2- The Modification Phase time should be-updated in the control charts after the implementation of the (SBT) Program. Then, each A/P maintenance and overhaul process has to be-monitored and charted in Control chart & reviewed to ensure a controlled process.
3- the emphasis on changing the culture of the work on the A/P and eliminates the uncertainty and confusion from the use of a new way of developed technology and give strict directives to stop work immediately and not to proceed completing the task if the technician felt that he is doing a technical error.
4- The (SBT) program should be, circulated to all incoming airplanes.

Recommendations for Future Work

The future work should be:

1- Using the Simulation Based-Training Programs not only on the Modification phase but also on each other airplane maintenance and overhaul processes and analyzes the effect.
2- Discuss the possibility of establishing a local area connection with the management and the Information Technology Branch, at the airplane work place using Wi-Fi devices, which is a local area wireless technology that allows an electronic device (Tablet PCs) to exchange data or connect to the internet. Using those Wi-Fi devices in order to, connect all the Tablet PCs through an intranet so that, all the processes done on the airplanes can be, monitored and controlled by the management.

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