A Case Study of Total Productive Maintenance Implementation in an Aircraft Maintenance Company

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Abstract

Total productive maintenance was introduced to USA in the late 1980s as a companywide strategy to increase the effectiveness of production environment. In recent years, many companies have attempted to implement this strategy to maximize equipment's effectiveness and productivity, and minimize machine losses. In this study, main concern is how a aircraft maintenance company can apply TPM, in an efficient way. In case study we determined the steps of the maintenance proscess and then analyzed tools efficiency with using overall equipment efficiency. Needed information is gathered from calibration standars which are determined by the manufacturers of the company.

Keywords: Total productive maintenance, overall equipment efficiency, maintenance repair overhaul, aircraft maintenance, calibration

1. Introduction

In the twentieth century companies start to implement mass production because day by day the business environment is becoming more competitive. This provides more products and cheaper price. More working employees are not the only solution for this. Furthermore, dividing the process into steps and equipment maintenance is needed for mass production. Because of more usage, machine and equipment breakdowns increase. Breakdowns have to be reduced for more outputs. Not only that, the shortage of raw materials now focused attention on the levels of waste. Cutting the cost of losses became a serious consideration. As if all this was not enough, the manufacturing equipment designs were increasing in complexity and required an even higher level of skilled support to operate and maintain those (Borris, 2006).

Total productive maintenance (TPM) can be described as a program which involves a newly defined concept for maintaining plants and equipment. The goal of TPM is to increase production while, at the same time, increasing employee morale and job satisfaction. (Muniswamy, 2008). Companies practicing TPM achieve startling results and TPM methods also improve equipment systems, operating procedures and maintenance and design processes to avoid future problems. (Productivity Development Team, 2004).

2. Total Productive Maintenance Literature Review

Total Productive Maintenance is a Methodology originating from Japan to support its lean manufacturing system. It was introduced to U.S.A. in the late 1980s as a companywide strategy to increase the effectiveness of production environment, especially through methods for increasing the effectiveness of equipment. In recent years, many companies have attempted to implement this strategy but 10 percent or less of the companies have succeeded. Companies are still looking for a holistic approach to reform how they operate in the new environment (Liu, 2004). TPM originated in Japan and was an equipment management strategy designed to support the Total Quality Management strategy. The Japanese realized that companies cannot produce a consistent quality product with poorly-maintained equipment. TPM thus began in the 1950s and focused primarily on the preventive maintenance.

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As new equipment was installed, the focus was on implementing the preventive maintenance recommendations by the equipment manufacturer. A high value was placed on equipment that operated at designed specifications with no breakdowns.

During the 1960s, TPM focused on productive maintenance, recognizing the importance of reliability, maintenance, and economic efficiency in plant design. This focus took much of the data collected about equipment during the 1950s and fed it back into the design, procurement, and construction phases of equipment management. Then in the 1970s, TPM evolved to a strategy focused on achieving PM efficiency through a comprehensive system based on respect for individuals and total employee participation. By the mid-1970s, the Japanese began to teach TPM strategies internationally and were recognized for their results. This process was an evolutionary one that took time, not be-cause it was technically difficult to produce the results, but because of the efforts to change the organizational culture so that it valued the "Total" concept.

Today the international focus on TPM is intensifying. This interest is expressed to support a company's full utilization of its assets (Wireman, 2004). The benefits of TPM implementation can be outlined in three categories as business, equipment and people. These are,

- *Business benefits;* (i) Planning with confidence through the supply chain to provide what customers want, when they need it, just in time, right first time. (ii) flexibility, being able to react quickly to market changes without high levels of stock and (iii) improvement in overall equipment efficiency as a measurable route to increased profitability.
- *Equipment benefits;* (i) Improved process capability, reliability, product quality and productivity, (ii) economical use of equipment throughout its total service life starting from design, called TPM for design or early equipment management and (iii) maximized efficiency of equipment.
- *People benefits;* (i) Increased utilization of hand/operational skills, team working and problem solving skills, (ii) practical and effective example of team working, including TPM in administration for the support functions and (iii) trouble free shifts, because value-adding activities become proactive rather than reactive (Willmott, McCarthy, 2001).

TPM is successful to achieve its avowed goals only if the participation of each and everyone is total and sincere. For such a system like TPM, since there is involvement of everyone in the organization, from the operators to top management, the expectations run very high. If the results achieved do not match the expected ones, the reactions can vary from snigger to dejection to frustration. In such cases, the reasons do not become apparent many times and hence the system of TPM itself is blamed. Some such pitfalls are ;

- TPM initiative starts with autonomous maintenance where in the production workforce is encouraged to do maintenance work is relating to their equipment and machine. This sometimes sends signal to maintenance department that it will be downsized. This tends to generate a feeling of resentment towards TPM from a big obstacle in its success.
- In certain cases, a company tries to implement TPM by trying the model of another company. This type of copying proves counterproductive since each company has its own unique culture, so results are unsatisfactory for TPM performances. Hence each company should evolve its own model of TPM implementation strategy.
- TPM implementation in any organization cannot be done overnight throughout the plant. It requires resources too. If the process of adaptation into the total system leaves very less funds to each area, the implementation cannot be successful. It is always better to mark the critical areas, bottlenecks or critical equipment to begin with and then allow the system to gradually spread to other areas.
- TPM involves everybody from top to bottom in an organization. In this light, it is worthwhile that the organization evolve a system of giving recognition to workers doing exemplary bit of work. If there is already a system, it must be modified to suit the goals of TPM.

When one goes through the above pitfalls, it becomes clear that TPM policy adoption is not a simple order and execution type of work and any deviation from the avowed goals could prove disastrous. The lack success of the TPM could be squarely put at the doors of partial or unfocussed TPM efforts.

TPM comprises of eight different sections which have come to be known as pillars. Each pillar has its own areas of responsibility, but they also have areas where they overlap. The descriptions below concentrates on those that are most related to maintenance and productivity. The pillars are identified as follows:

- *Health & Safety:* This pillar is so important because it sets zero accidents. Its importance is emphasized by the need to protect operators, who will be trained to carry out simple technical tasks.
- *Education & Training:* Without proper training TPM will simply not work. It is so important that what knowledge is necessary, how to teach it, and how to confirm it has been absorbed and has been understood.
- *Autonomous Maintenance*: Using highly skilled technicians or engineers to carry out very simple tasks is not cost effective. If operators could be trained to carry out these basic tasks, it gives them an opportunity to increase their skill level, makes them more responsible for the operation of the tool, increases their job prospects, and frees up the technicians to work on more complex tasks.
- *Planned Maintenance:* Planned maintenance looks for the underlying causes of equipment problems and identifies and implements root-cause solutions.
- *Quality Maintenance:* This pillar utilizes cross-functional teams to analyze areas of equipment performance where the product variation should be reduced.
- *Focused Improvement:* There will be outstanding issues with equipment or processes that have been difficult to identify in the past. Cross-functional teams are used to investigate the issues and to find permanent solutions. The problems under consideration have to be evaluated to justify if a fix would provide a positive, cost-effective benefit.
- *Support System:* This pillar uses TPM techniques to identify and resolve problems. These problems can be problems as lack of spares, incorrect spares, excessive lead times, poor quality materials, lack of standardization of dimensions of materials, parts shipped with the wrong specification, parts not arriving on time.
- *Initial Phase Management:* This is the organizational or planning pillar. The methodology follows a kind of Value Flow Analysis (Borris, 2006).

3. Case Study

The globalization of aviation is one of the most impressive developments in the economic environment that we are living in. Global mobility of people and goods with almost no restrictions as to time or distance enables many companies to become global players in their industries. Most of these industries achieve growth through globalization. This growth drives rapid development of the aviation industry, as more people fly and more goods are transported (Henningsen, 2008).

In parallel with rapid developments in aviation industry, aircraft manufacturing, maintenance, repair, modification and systems integration on issues such as life and property safety of flight with a very great progress has been made to ensure the highest level of safety. Features from the 1970s, both international civil aviation organizations and the country as well as civil aviation aircraft manufacturer authorities the risk of accidents by targeting legal arrangements and accordingly, due to publish maintenance schedules, as well as all over the world in our country, aircraft maintenance, repair and renovation services gained great importance.

3.1. Maintenance, Repair and Operations (MRO) Industry in Turkey

In Turkey, civil aviation sector aircraft maintenance services started with the establishment of the State of the airways in 20th May 1933 which is the core of Turkish Airlines. The maintenance of the aircrafts was taking place in two medium size hangars and in little workshops at Ankara Güvercinlik Airport. Engine revisions were taking place at Turkish Bird Aircraft factory at Etimesgut.

In the beginning maintenance activities was taking place by technologic and training support of aircraft manufacturers. Over time national facilities were built up, engineers and technicians were trained and this decreased the dependence of overseas. In 1945 Turkey joined to International Civil Aviation Organization (ICAO). Following this aircraft maintenance functions gained a regular structure. Since 1955 maintenance activities have been started to implement at Yeşilköy Airport. Turkey joined European Civil Aviation Conference in 1956. As a consequence of this aircraft maintenance, repair and aviation functions have been done in the same parallel and standards with European countries.

In 1978 by the construction of a new hangar Turkish Technic started to implement all maintenance activities in its hangar. In 2000 by the step of the second hangar THY increased maintenance capacity, improved maintenance service and became an international maintenance company. In 2001 Turkey became a full member of JAA/EASA. By the accomplishment of “Regional Aviation Project” in 2003 Turkish Civil Aviation increased its passenger number. Turkey rank among the top three in contour in the world. According the International Global Market Research for the next 20 years Turkey will be the fast growing country in domestic flights in the world. The number of wide-bodied aircraft increased from 100 to 332. The number of employment increased from 4800 to 110000. In this period regional cooperation agreements are made with 11 countries.

3.2. Implemantation Process

XXX Aircraft MRO Services is established in 2007 as a Lean Aircraft MRO Service located in Sabiha Gökçen International Airport on the Asian side of the Istanbul. During the study, company which case study took place called as XXX Aircraft MRO Services. XXX company approved by Turkish DGCA, JAA and EASA carries out maintenance and repair works only on aircraft, engine and components within it is approved scope in its facilities and stations.

Maintenance activity starts with the acceptance of the proposal by the customer. Commercial department informs pre-induction department about the arrival time of the aircraft. They inform and provide customer contact information. They form and work request for the maintenance package of the aircraft to cost control department and then a work order number is determined for the specified maintenance.Then pre-induction starts to examine the work package of the specified aircraft. Work package consist from tally sheet which includes the items that has/must be performed during the maintenance activity. Table 1 shows a page from the tally sheet of XYZ aircraft.

Table 1. Tally sheet of XYZ aircraft

SR Technics				Performed operations				TALLY SHEET
JCID	Work area	Noti number Order number Operation number	Noti type	Notification description Order description Operation description	Work center	Sign task code TL Number Revision date	Date	Signed by
1	1000	401902807 35647471 0010	AO	ewr 23-ao-401902807 hf inspection ewr 23-ao-401902807 hf inspection a/b ewr 23-ao-401902807 this requires an	out ex	/		
2		401833315 35616883 0010	AM	sb/737-53A 1200_000_00 fwd.galley sb/737-53a 1200_000_00 fwd.galley sb/737-53a 1200_000_00 fwd.galley	out ex	/		
3	0000	401665505 35695525 0010	AC	hanger c-check 737 c-hangert pre-check safety checks pre-check safety checks	out ex	766358 / 2 09.10.2006		
4	0100	401665505 35695530 0010	AC	hanger c-check 737 c-daily check law worksheet Daily-check law worksheet	out ex	766358 / 1 09.10.2006		
5		401990108 35695958 0002	AP	get/close access for event 2115616 get access for event 2115616 all 0100	out ex	/		
6		401990108 35695959 0002	AP	get/close access for event 2115616 close access for event 2115616 all 0100	out ex	/		
7	0400	401665495 35695613 0010	AC	sama fc check b12-04-sam fluid sampling flied sampling	out ex	710448 / 1 10.08.2007		
8	1000	401889334 35695469 0010	AM	Sb737-53a1197 body station30/3.9 initial inspection – part 1 initial inspection – part 1	out ex	A 787486 / 1 11.09.2008		
9	1000	400617023 35695147 0010	AC	sama 2c check b24-02-sam component component	out ex	787495 / 1 12.12.2008		

10	1000	401665495 35695565 0020	AC	sama 1c check b34-11-01-2a pilot-static drains-nose pilot-static drains – nose w/w	out ex	711062 / 1 10.08.2007		
11	1000	400861755 35695144 0010	AM	sb/737-53a1210_000_01 part 2 ext ndt sb/737-53a1210_000_01 part 2 ext ndt perform work	out ex	A 766857 / 2 13.12.2006		
12	1000	400658856 35695144 0020	AV	c53-100-01 pt5 corrosion prevention c53-100-01corrosion prevention fuselage exterior surface - lower lobe	out ex	766740 / 1 10.08.2007		
Print date: 13.01.2009 Print time: 09:48:50 HZ-DMO 2115616								

Proposal step form's a list which's name is ApxA to inform customer about details. It is the "Remarks" column. If there are any notes about the tasks we note them and by this way we inform customer. This prevents misunderstandings. Table 2 shows an appendix example.

Table 2. Appendix Example

#	CUSTUMER TASK CARD REF	TASK DESCRIPTION	REFERENCES	CUSTOMER REMARKS	"Company Remarks"
1	B12-15-31-3A-1	SERVICE THE LEFT MAIN GEAR SHOCK STRUT.	0		Only removal & installation is included in the fixed price and span time requirements. If new part is not provided by customer; shop works will be considered as additional work
2	B12-15-31-3A-2	SERVICE THE RIGHT MAIN GEAR SHOCK STRUT.	0		
3	B12-15-41-3A	SERVICE THE NOSE GEAR SHOCK STRUT.	0		Not included in the fixed price and span time requirements. Please provide further information
4	B12-22-11-3A-1	LUBRICATE THE LEFT WING AILERON COMPONENTS.	0		

After examination of the work package items are numerated according to customer task number and turned into company number. After preparations items are saved under the specified work order number of the aircraft. By this way it forms a rowed bunch. Maintenance system sequences items. By sequence systems tracking the cards are easier.

While preparation of the work package pre-induction department forms two cards except the task card of the item. First one is"tracking card" includes the short description of the work, a colored little box which is color according the type of the task and the abbreviation of the task type. This card is designed for easy tracking of the cards on hangar floor. Second card is maintenance job card. Maintenance job card includes; customer name, workorder number, issue date, type, check type, station, task type, special requirements, prerequisities, description of work, maintenance data, material used, possible dual system maintenance, duplicate inspection, tools, equipments, consumable material, expendable material etc. This information is automatically filled by maintenance system by using task card database. These are necessary for maintenance and maintenance records. In aviation sector every job has to have a reference about who done the job. Because every job has a different authorized technician. Every section of the aircraft has special province. That's why maintenance job card includes done by and cert by columns for technicians stamps.

According the list of works pre-induction prepares a material list of the specified aircraft and inform system department about this. They check materials codes and then send it to material planning department. Material list is composed from three parts as Tool, Consumable and Expendable. Table 3 is an example of tool list.

Table 3. Tool list

MPD TASK	TOOL&EQUIPMENT NAME/KEYWORD	DESCRIPTION	QTY	SUPPLIER/ MANUFACTURER	MST REMARK	SELECTED PN	AMM REF.
B12-13-21-3A-1	ADAPTER, HOSE	ADAPTER - HOSE, COUPLING	1	OZONE METAL PRODUCTS	included in GSEs.	736-013	AMM 71-11-02/201
B12-13-21-3A-1	CART	SERVICE CART	1	MALABAR HYDRAULICS CO.	included in GSEs (IDG Servicing)	PF53361-16P	AMM 71-11-02/201

Material planning department can check the tools in our Tool Store from the Inventory management tool report part. To improve equipment effectiveness tools those are used while maintenance activities of an aircraft are periodically calibrated. They are store according to alphabetic order in the tool store. And their conditions are updated according to calibrations. Table 4 is an example of consumable list and table 5 is an example of expendable list.

Table 4. Consumable list

MPD TASK	MATERIAL NAME / KEYWORD	DESCRIPTION / SPECIFICATION	QTY	MANUFAC-TURER/ SUPPLIER	MATERIAL CODE	PART NO	EFFECTIVITY	REF
B12-13-21-3A-1	OIL	OIL - AIRCRAFT TURBINE ENGINE, MIL-PRF-23699, TYPE II	AR	86961	D00068	AEROSHELL TURBINE OIL 500	CFM56-3	AMM 71-11-02/201
B12-13-21-3A-2	OIL	OIL - AIRCRAFT TURBINE ENGINE, MIL-PRF-23699, TYPE II	AR	86961	D00068	AEROSHELL TURBINE OIL 500	CFM56-3	AMM 71-11-02/201

Table 5. Expendable list

MPD TASK	SRT	MATERIAL NAME / KEYWORD	DESCRIPTION / SPECIFICATION	QTY	PART NO / MATERIAL CODE	IPC REF.	REF. AMM
B12-13-21-3B-1	E	PACKING	PACKING	1	M83248-1-902	24-11-11-01A-25	AMM 24-11-11/601 AMM 71–11–02/201
B12-13-21-3B-1	E	PACKING	PACKING	1	M83248-1-905	24-11-11-01A-30	AMM 24-11-11/601 AMM 71–11–02/201

By this pre preparation related departments can see which material is going to be used at which work. If there is a missing material they can provide it before the arrival time of the aircraft. After the material planning department is informed about the materials list they can double check lists with the list that maintenance planning system prepares and pre-induction department prepares. System prepares this list form task card database from the previous data's. By this way they prevent unnoticed material information.

According to component movement list component are removed by the arrival of the aircraft and then send to shop for operation. It is one of the important works for the aircraft because usually component operations take more than one day. These steps are necessary for the planned finished date of the aircraft. After these steps planning department has the responsibility of the work. They prepare a gant chart for the proper running of the tasks.

For overall equipment efficiency calculation we use calibration measurement values and calibration standards which are determined by manufacturers and company. Every tool is a history in inventory management system with its specifications. These specifications are location, amount, barcode, part number, equipment long description, serial number, batch number, shelf number, status, manufacturer, category, usages etc.

3.3. Calibration Procedure

At first time to assign calibration period for a device following requirements are considered:

- Legal regulation and arrangements
- Type of equipment
- Specifications of device
- Manufacturer's recommendation
- Trend data obtained from previous calibration records
- Extent and severity of use
- Recorded history of maintenance and servicing of device
- Frequency of cross-checking against other reference standards or measuring devices
- Checking of measurement accuracy
- Environmental conditions of device while using
- Experience/know –how of persons using the device

For each device calibration laboratory chief determines a preliminary calibration period according to these steps. And in time evaluates this period if necessary he/she makes changes to this period. For every device average calibration (CP0) interval is determined according to manufacturer advices or experiences or theoretical calculations. To determine beginning (CP1) interval we use some tables. Table 6 informs about factors which affects devices.

Table 6. Factors which effects devices

No	Factor Name	Factor Value "0"	Factor Value "1"	Factor Value "2"	Estimation
1	User know-how	Low Level	Normal	High Level	x_1
2	Humidity	%60 ± 30	%50 ± 15	% 50 ± 5	x_2
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i	Factor i				x_i
n	Factor n				x_n

First interval can be calculated from the data obtained from this table by following equation;

$$CP_1 = CP_0 * \sum_{i=1}^{n} \frac{x_i}{n} \tag{1}$$

When determining the calibration period at first time all affects which can affect these choice has to be determined. Calibration Laboratory Superintendent is taking care to these factors while determine the first interval and use the equation above. When necessary, device users and/or related directors assure him/her usage and technical information. Table 7 informs about factors and their importance by determining calibration interval for devices.

Table 7. Factors and their importance

1	**Physical specifications of device**	**Sensitive, corrositive**	**Normal**	**Strong, resistant**
2	Importance at using location	High level	Normal	Low level
3	Effect of product tolerance	High level	Normal	Low level
4	The risk of a measuring instrument going out of tolerance when in use	High level	Normal	Low level
5	Estimated accuracy of device	Bigger than max. permissible measurement error	Equal to max. permissible measurement error	Smaller than max. permissible measurement error
6	Type of usage	Moveable	----	Stable
7	Severity of use	Too high	Normal	Too few
8	Number of users	> 3	2-3 persons	< 3
9	Usage conditions	Construction side	Workshop	Laboratory
10	Knowledge of users	Low level	Normal	High level
11	Humidity of ambient	% 30-90 RH	% 35-65 RH	% 45-55 RH
12	Temperature of ambient	10 – 40°C	18 - 28°C	21 – 25°C
13	Vibration of ambient	High Level	Normal	Low Level
14	Dirtiness and dust of ambient	Available	Acceptable	Very low level
15	Results of random errors	High level	Normal	Low level
16	Manufacturer advice (If there is)	Lower than recommended value	Recommended value	Higher than recommended value
17	Verification frequency	< 2	2 – 4	> 4

After determining the first calibration period any change and measurement done to calibration intervals until the second calibration. Device is evaluated after the second calibration. If there are no differences from the acceptable certificate values this interval is left same. But if values are above or below the acceptable values the calibration interval of the device is made shorter properly. If there is not any changes and if needs the interval can be made longer. While making the interval longer or shorter, criterions this procedure are overviewed. Table 8 informs about advised CP0 values for calibration interval.

Table 8. Calibration example

MEASURING RANGE		DIMENSIONAL	
Item number	Device	Beginning Calibration Interval CP_0	Calculated Calibration interval
01	Gauge block	12 Mo	20 Mo
02	Long gauge block	12 Mo	20 Mo
03	Plug gauge	12 Mo	20 Mo
04	Wire or prop gauge	12 Mo	20 Mo

4. Conclusion

To prevent breakdowns maintenance is so important for a company. It reduces overall company cost because production capacity is available when needed. It can be defined as the most important support function of a company by providing continuousness. This study identified and analyzed Total productive maintenance based on present literature and published books, the effects of TPM and its usage in MRO. For an aircraft maintenance company adoption of TPM is necessary for a successful implementation. After implementation, control and audit is necessary to provide continuity.

While applying maintenance activity technicians' needs measurement and test devices like tools. To make maintenance activity continuous and prevent disruptions tools has to be stored and maintained properly. XXX Company has a tool store where every tool is set in order in an alphabetic order according to their frequency of occurrence. Frequency of occurrence is reported by tool store year by year, month by month according to usage quantity. There is calibration procedure ,which is mentioned before, to provide confidence of these tools and this procedure contains all test and measurement devices which are needed to be calibrated.

Calibration value are used to calculate overall equipment efficinecy which is one of the indicator for TPM. OEE is used to measure utilization of machines and gives the overall utilization and shows the loss factors in detail. By using OEE, we can categorize losses in order to decrease up to an applicable level.

OEE can be used to measure the performance of equipment or to determine the bottlenecks. OEE has 3 parameters, availability, performance and quality. Overall equipment efficiency is the product of the availability, the performance, and the quality (Borris, 2006). All needed information for computation of OEE in XXX company can be gathered by calibration procedure so comapny uses its frequency reports effectively.

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