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# Application of Lean Methods into Aircraft Maintenance Processes

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**Abstract.** Aircraft Maintenance and Repair Organizations (MRO) have to be competitive and attractive for the existing and new customers. Aircraft ground time at the MRO has to be as short as possible as well as cost efficient without reducing the quality of the accomplished work.

Application of lean methods into aircraft maintenance processes means continuous improvement process and elimination of non-value-added activities during the maintenance check. There is on one hand an obligation to follow the prescribed procedures and on the other hand a pressure for the time and cost reduction. The paper presents the application of lean methods to the aircraft maintenance processes. A comprehensive study of lean methods has been done in the first phase. Selected methods were then applied as pilot projects. The promising results have focused activities to the optimization of logistics. Several conclusions from the pilot project can be generalized to similar processes and organizations.

Keywords. Lean methods, aircraft maintenance, MRO, Lean, value-added activities, concurrent engineering

## Introduction

Since aircraft traffic is rapidly growing, MRO market is also growing. A lot of world aircraft operators are buying new aircraft in order to reduce operational and maintenance costs. In the last years the fuel price had a big impact to the operational costs. Consequently, more pressure was focused to the reduction of the maintenance costs for keeping profitability. Therefore MROs have to find their internal reserves, they have to optimize internal processes and they have to be focused to satisfy their customers with the goal that customers will return and ask for another check.

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Generally in the aircraft business, the rise of the new competitors will enforce continuous consolidation in the entire supply chain, like it already had been experienced in the automotive industry during the past two decades [1].

On the other hand, the structure of MRO has to be very well adapted to the specific aircraft type and required maintenance type. Man power has to be experienced, tooling has to be adapted and the stock of spare material has to be adapted to the needs and expectations, based on the experiences from the previous checks as much as possible.

MRO business is based on the projects and depends on the specific aircraft conditions [2]. This means that the majority of the job is defect-based and it cannot be completely predicted in advance. In some cases (on the basis of the previous similar aircraft checks, aircraft flight hours and flight cycles) the prediction of the condition of the aircraft is possible, but there can always be surprises in a positive or negative way.

Lean manufacturing approach was originally developed for the production environment with pre-defined job steps which were continuously repetitive through the manufacturing cycle [2]. Therefore some adjustments have to be made on the lean tools and principles to be adaptable with MRO business. Anyhow, the goal is to improve the organization's performance on the operational metrics which make a competitive difference by drawing employees in a hunt to eliminate waste. Before implementing lean thinking it is recommended to measure the readiness of the enterprise for the introduction of lean into the current processes [3].

### **1. Basics of lean theory**

There are five lean principles [4]:

- Value
- Value Stream
- Flow
- Pull
- Perfection

M. Jasiulewicz - Kaczmarek wrote that the lean manufacturing is the practice of eliminating waste in every area of production including customer relations (sales, delivery, billing, service and product satisfaction), product design, supplier networks, production flow, maintenance, engineering, quality assurance and factory management. Its goal is to utilize less human effort, less inventory, less time to respond to customer demand, less time to develop products and less spare to produce top quality products in the most efficient and economical manner possible [5].

For C. Jagadees lean maintenance is not a cost cutting tool, but a methodology to reduce waste and improve maintenance efficiency. Reducing waste leads to cutting costs, but cutting costs does not always lead to reducing waste [6]. Apparently, elimination of these wastes looks simple, but their identification is often difficult [7].

Application of lean methods into aircraft maintenance processes means application of continuous improvement into aircraft maintenance process. One of the most important aspects of lean maintenance is developing an understanding of the maintenance process [8]. The goal is to minimize waste in terms of non-value-added activities, such as waiting time, motion time, set-up time, etc. [9].

Lean maintenance means delivery of maintenance services to ultimate customers with as little waste as possible. This means elimination of everything in the maintenance value stream that does not add value to the customer or product [6]. Value creation and understanding of value from the perspective of the ultimate customer are two basic items in lean [10].

For MRO the ultimate customer could be considered as the aircraft operator who wants the maintenance to be done on time and within budget, the pilot who requires that all the equipment operates within specification all the time, the passenger who requires the aircraft to depart on time and the entertainment system to operate, the airworthiness authorities and manufacturers, which have standards to be adhered [4]. There are three different types of value activity within an organization [4]:

- Value-Adding Activities (VAA) Activities which are valuable through the eyes of the customer (the customer is prepared to pay for them).
- Non-Value-Adding Activities (NVAA) These activities are all the activities which the customers consider non-valuable and present waste Muda.
- Necessary but Non-Value-Adding Activities (NNVAA) These activities are for the customer considered as non-valuable, but are necessary in the process.

Muda – Japanese word for waste and is central to understanding value. Wastes are categorized into seven Muda types (Inventory, Motion, Over-production, Waiting, Processing, Corrections and Transportation).

Value stream map is a tool which helps to visualize a system by the representation of information and material flow [11].

# 2. MRO Environment

Basically aircraft maintenance can be divided into Line Maintenance and Base Maintenance:

- Line Maintenance activities include pre-flight checks/technical assistance, daily/weekly checks, aircraft servicing, refueling/defueling assistance, de/antiicing, supervision control, coordination of unscheduled technical support etc. These types of checks/activities usually require short stoppages of the aircraft.
- Base Maintenance activities require longer ground time of the aircraft and are planned in advance in accordance with aircraft flying hours/cycles. This group includes C-checks, D-checks, 6-Years-checks, 12-Years-checks and other heavy maintenance checks. Usually many unpredicted defects are found there.

On the other hand, MROs can be classified by using various criteria [12]:

- Classification of the MRO Industry, based on the 'type-function':
  - Heavy Maintenance Visit
  - Engine Overhaul
  - Component Overhaul
  - Line Maintenance
  - Avionics
  - Retro-fits and Conversions

- Classification of the MRO Industry, based on the Organizational Structure:
  - Independent / Third party MRO Organization
  - Airline Operated / Owned MRO Organization

## 3. Analysis of a typical project in MRO organization through the lean eyes

The analysis of the process was done on one of the European MRO. On its capability list you can find line maintenance checks, A-checks, C-checks, D-checks, 6Y-checks, 12Y-checks on Airbus A320 family, Bombardier CRJ100/200 and Bombardier CRJ 700/900/1000 family. Beside these, QEC (quick engine change) removal/installation and inspection, line maintenance and troubleshooting on V2500, CFM56-5, CF34-3 and CF34-8 aircraft engines can be found on their capability list.

10 days C-check on Airbus A321 aircraft was taken as a sample check for this analysis. The check itself was planned approximately a month in advance. Project members from engineering, purchasing and operative department were known two weeks before aircraft came into hangar and customer representative was announced 2 days before the start of the check in hangar. Work-orders were checked 10 days and spare material was ordered one week before the start of the check. Approximately 70 NRC (Non-Routine Cards) / defect cards were raised during the check. Project was extended for one day.

As shown in Figure 1, sample check was first analyzed in a sense of definition of project milestones and project phases. After that the estimation of time-schedule for project milestones and project phases within the time period given to the project was carried out. In the third step the existing main tasks were analyzed in a sense of their duration and the ratio between VAA / NVAA was calculated. In the fourth step of the analysis the main mechanics and heads of each work-shop completed the questionnaire about project anomalies data collection – Muda and project deficiency. They were also asked about possible improvements for each Muda or project deficiency. In the last, fifth step, a new time-schedule of main tasks and new ratio between VAA / NVAA on the basis of the questionnaire results were calculated.

During the project analysis all the implemented work activities were divided into two groups: VAA and NVAA group.

VVA group included the following activities:

- Inspections On the basis of these activities the customer is allowed to extend the aircraft airworthiness and therefore they represent VAA.
- Modifications After the accomplishment of the requested modification, the customer expects positive impact on aircraft D&C Rate (Delay and Cancellation Rate), ABTO Rate (Aborted Take-off Rate), IFSD Rate (In Flight Shut-Down Rate), SV Rate (Shop Visit Rate), etc. and consequently lover operational costs and therefore these activities also represent VAA.
- Incoming defects Usually these defects are known from the near past and were deferred till the aircraft maintenance check. At the time of the check customer knew about them and wanted to eliminate them. Therefore these activities also represent VAA.

On the other hand, all the findings, discovered during the check, present new/additional costs for the customer and therefore belong into NVAA group.

NVAA group includes all the activities in the next sub-groups:

- Acceptance
- Preparation
- Defect Rectification (just Findings)
- Close-up
- Tests



Figure 1. Analysis Flow Chart.

As shown in Figure 2, it was discovered that almost 2/3 of all the work represent NVAA and only 1/3 of the implemented work represents VAA.

A comparison between the used working hours for every project phase has been done. After a closer look to Figure 3 it can be observed that the preparation and the close-up phase together take 37,5% of the used project hours, which represents more than all the used hours for VAA (34,35%) together. If we also add the Findings part of the Defect rectification phase, they represent 58% of the total project time.



Figure 2. Work activities ratio between VAA and NVAA and time consumed percentage of each phase of work.

Further on, unnecessary project events, which have negative impact on the used working hours and consequently to the final project price, were analyzed. The most exposed events, irrespective of the group into which they belong, were:

- Tooling loan was planned for the first day of the check, although it was known in advance that it will be needed on the 3<sup>rd</sup> day of the check.
- Due to the simultaneous start of more projects (aircraft checks) on the same day, there was a lack of manpower in the first days of the project. Consequently, the preparation and inspection phases were completed one day later. The ground time of the aircraft was extended for one day.
- Due to the aircraft position in the hangar 1 some work-shops were not close (just on the opposite side) to the aircraft. Consequently, many parts transportation and man-power motions were required during the inspection and the re-assembly phase of the project. In Figure 4 ways from the aircraft to the composite and paint work-shop and from the aircraft to the cabin and interior work-shop are shown [13].



Figure 3. Work activities sub-groups portions.

- A lack of some consumable material was discovered in the middle of the check. It had to be additionally ordered on a higher priority level and was consequently more expensive.
- In the re-installation phase of the project a few man-hours were lost due to the waiting for the material. The particular material could not be released from the store due to certificate issues.
- Due to the aircraft flight hours / flight cycles and in advance known job cards (inspections) of the project, some spare material was ordered in advance on the basis of the previous experiences and expectations, but later on it was not used during the project.
- On the last day, the aircraft departure was delayed for a few additional hours because of the uncompleted work orders, which could easily be closed one day before the end of the project.



Figure 4. Analyzed Aircraft position in hangar.

If you are looking through the lean eyes all the above events present NVAA or waste and as such they are unnecessary in the project and have to be eliminated from the process.

## 4. Corrective Actions

Generally, improvements and other changes are always implemented during regular processes, therefore they must be performed or implemented rapidly to prevent delays [14]. In case of any interruption during the improvement implementation, the possibility for quick reaction in a sense of final solution implementation has to be available. It should be taken into account that process improvements always involve high level of unpredictability [15]. Frequently, the additional research, cooperation with external suppliers, customers, authorities and other approvals are required.

Figure 2 shows that the most time consumable NVAA portions of the project are:

- Preparation phase
- Close-up phase
- Finding part of the Defect rectification phase

Therefore, the biggest impact on the project working hours and costs savings in combination with elimination of unnecessary project events can be found in the above mentioned three phases. Various suggestions on the basis of the questionnaire were checked. Below, the most promising are listed: Preparation phase:

- Due to in advance known type of inspections and consequently in advance known requests for access panels and passenger seats removal, aircraft should be positioned closer to the composite and cabin work-shops, where the panels and passenger seats are inspected and repaired. The optimum position would be in Hangar 2. Hangar 1 should be used for other types of checks. The estimation of the time saved for access panels and passenger seats removal is more than 13%. This is quite a huge number, but taking into account that all the passenger seats, all the cabin interior panels, all the floor panels, galleys and toilets are closer to the composite and cabin work-shop, the number becomes more reasonable. This action reduces Muda of Transportation and Muda of Motion. In Figure 5 better aircraft location regarding check type is shown.
- Due to the simultaneous start of more projects on the same day (although unplanned) the lack of manpower occurred in the preparation and inspection phases. At every sub-phase of the preparation phase some time savings can be gained with a proper planning of manpower. This action reduces Muda of Waiting.
- By starting the loan period on the day, when the tooling is required, loan costs of the tooling can be reduced. This action reduces Muda of Over Production.

Close-up phase:

- Similar as in the preparation phase, Muda of Transportation and Muda of Motion can be reduced due to a better position of the aircraft in hangar.
- Component's certificate issue extended installation time of the particular component for 2 hours. By settled certificates 2 hours or 6,7% of the installation time of the particular component could be gained. This action eliminates Muda of Waiting and Muda of Correction.
- Duly closed work-orders reduce time in the Close-up phase. This action eliminates Muda of Waiting.

Finding part of the Defect rectification phase:

- Delivery time for some spare material, for defect rectification, can be reduced by completing the inspection phase earlier (sufficient manpower). This action eliminates Muda of Waiting.
- By eliminating a lack of consumable material, time and cost savings in the process are possible. Although it is difficult to estimate the savings, the material on time and on position presents savings in the project. This action reduces Muda of Waiting.
- In aim to be well-prepared for the project, some spare material (component) was ordered on the basis of the previous experience. However, afterwards it was not used on the project, because there was no finding. The component was returned to the supplier, two way transportation costs and return fee to the supplier had to be paid. Due to the planned 10 days check, the particular

inspection could be done just at the start of the project and the potential failure of the component could be confirmed or rejected on the first days of the project, which could allow delivering the component on time. This action eliminates Muda of Transportation and Muda of Inventory.



Figure 5. New Aircraft position in hangar.

As shown in Figure 6, after the implementation of corrective actions a new VAA presents 36,62% of all the activities. NVAA are reduced to 63,38% of all the project activities.



Figure 6. Work activities ratio between New VAA and New NVAA.

## 5. Conclusion

By the above mentioned actions 112 working hours could be saved for a particular project, or the project time could be reduced for 6,2%. As shown in Table 1, ratio between VAA and NVAA is changed for more than 2% in a positive way for VAA.

Table 1.	Corrective	actions	overview
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ACTIVITY	Before implementation of corrective actions	After implementation of corrective actions	CHANGE [%]
VAA	34,35	36,62	+2,27
NVAA	65,65	63,38	-2,27

This analysis presents the benefits of lean implementation into MRO organization. It is important that the changes do not influence the quality of the service, as well as that the changes in the processes positively affect the quality. Anyway, lean implementation into MRO processes requires close cooperation between the involved company departments, such as quality, marketing, engineering, operative and purchasing department as well as the top management. Beside this all the employees must be aware of the importance of the never-ending implementations of improvements into MRO processes.

By a careful definition of inputs, which present waste and NVAA into the process, further improvements of VAA / NVAA ratio are possible. With the implementation of some tools for optimization, like Genetic Algorithm, various wastes can be eliminated from the process and the best solutions for each individual project in a sense of aircraft position in the hangar, spare material, required tooling, man-power, etc. can be planned in advance with a higher level of reliability.

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