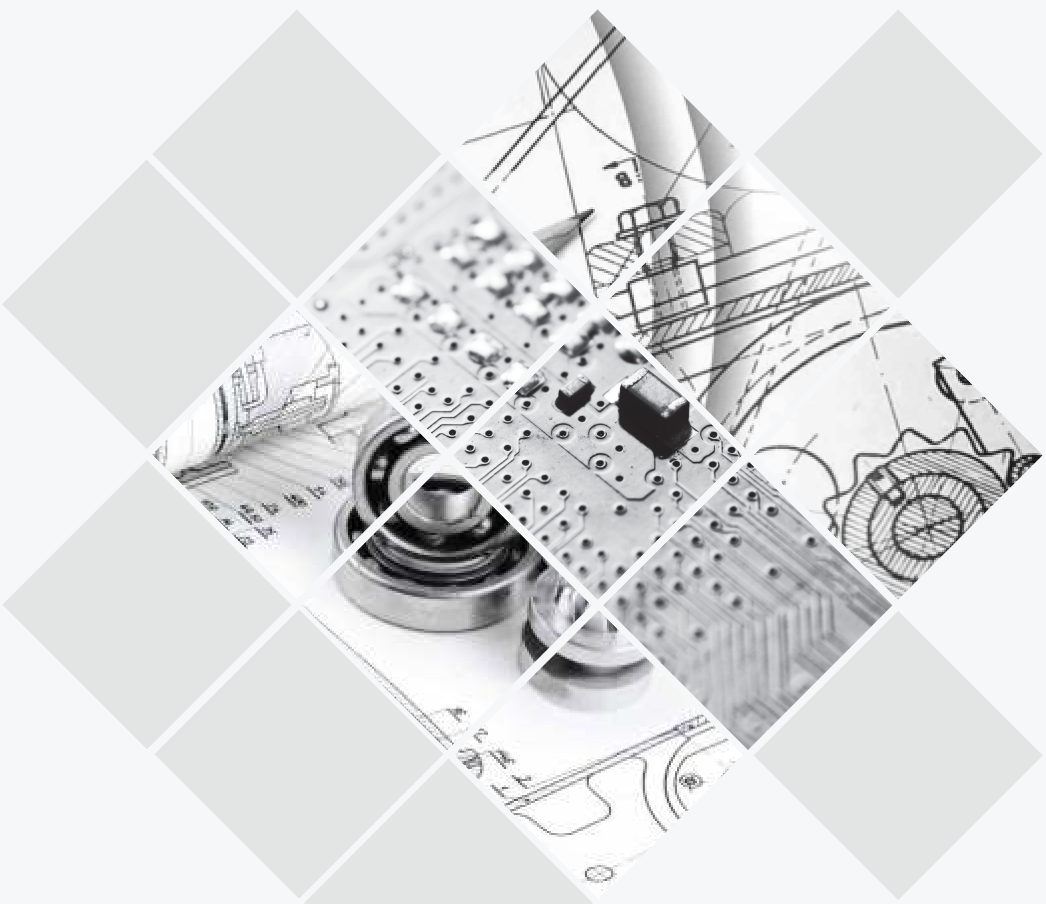
On-Field Event Management: Minimum Impact, Maximum Readiness



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Introduction

Aviation industry is a highly capital intensive industry. In the midst of intense competition, profit margins are getting squeezed by the day. Airlines and aero engine manufacturers are striving hard to improve their profit margins. It is a fact that their profits are directly related to the operational readiness of the equipment. A potential way of improving profits, therefore, is by reducing the maintenance expenditures and downtime.

Original Equipment Manufacturers (OEM) design and manufacture the equipment with theoretically robust reliability predictions. However, the actual performance of the equipment can significantly vary from predictions depending on the operating environment and other conditions.

Theoretically, aero engines and the associated hardware are designed to run seamlessly for their entire predicted life (e.g. 20,000 hours). In reality, this is hardly the case, and during the service operations, a variety of unpredicted faults like fluid leaks, high Exhaust Gas Temperature (EGT), and valves not closing will occur. These issues are termed as on-field events that lead to undue delays in operation, cancellation of flights, or in some cases, to an Aircraft-On-Ground (AOG) situation.

These unpredicted events cause interruptions leading to additional maintenance and penalties that finally eat up the profits. While these events are unavoidable, the impact on profits can be reduced if the operational impact of the events is minimized. To reduce the impact of the events, it is vital to have a well-structured event management (EM) mechanism.

Ideally, a well-structured EM process should have the following constituents:

1) Real-time data gathering
2) Data categorization
3) Data analysis to identify the key issues as well as repeating issues
4) Root cause analysis mechanism
5) Identification of corrective actions
6) Development and implementation of corrective action
7) Preventive improvement action

The following sections will describe the EM process constituents in detail, present a case study on EM, and summarize how EM capability at QuEST can help the customers decrease the cost impact of unplanned maintenance events.

Data Gathering

There can be various ways of collecting on-field event data. Airlines can maintain their data records of the events and share this data with the aero engine manufacturers on a regular basis. Alternatively, an online database (owned by the aero engine manufacturer and accessible to the airliners) can be an ideal way of capturing real-time data and ensuring availability of data to aero engine manufacturers for further processing. In the current scenario, most aero engine manufacturers have set up their online database systems with access to key stakeholders.

Data Categorization

The available event data should be categorized under various failure headings for allocating analysis activities to various departments. For example, the events related to the failure of the ignition system should be separated from the events related to the smoke in the cabin. The proper categorization will facilitate effective allocation of the events into appropriate areas for further analysis. The data should be segregated based on engine type. This is required so that the OEMs or suppliers will focus on addressing the relevant failure events rather than spending time in reviewing everything

Data Analysis

The data, post-categorization, should be analyzed in detail to understand the impact and root cause, as well as for identifying corrective actions. It is possible to include multiple domain experts in the cross-functional team for carrying out the data analysis for a single category of events because of the complexity of the systems and the various components and sub-components designed to perform a single function. For example, the function of Variable Inlet Guide Vanes (VIGVs) is to facilitate "prevention of engine surge" but an electro-hydro-mechanical mechanism controls operation of the VIGVs. So to analyze the events related to the failure of VIGVs, the data should be analyzed by electrical specialists, design specialists, and service engineers.

Similarly, an "Engine Failed to Start" event in the engine could be due to various reasons viz.:

i) No fuel supply,
ii) No ignition,
iii) Incorrect tuning of the engine controller,
iv) Failure of engine controller, and so on.

In such a case, there may be a need to integrate an engine specialist, electrical specialist, and electronic systems specialist to work together as a team and to investigate the event.

Root Cause Analysis

Once the event data has been scrutinized to identify various failures in a particular system, do the root cause analysis to reach the basis of the problem. The root cause analysis can be carried out by using standard statistical methods. A few of them are listed below:

a) Why-Why Analysis – This is an iterative technique to resolve a problem. The term WHY is used by asking sequential questions to identify the root cause of the problem. It is considered that by asking questions using WHY 5 times will guide us to the root cause of the problem, however, there still may be potential to ask a few more questions (may be 6 or 7). After identifying the root cause(s), suitable corrective or preventive actions should be defined and implemented. Involvement of the right set of people and asking the right questions is the key to the success of this process. The focus of the Why-Why analysis should remain on revealing the systemic issues rather than blaming the individuals. A spreadsheet comes handy in running this problem-solving method. Figure 1 shows a typical sample of a Why-Why analysis.

b) Event Tree Analysis – This method uses the forward prediction method, initiating from a significant event. A tree (refer figure 2) of possible events that are expected to happen, leading to multiple conclusions, is plotted. An analysis of each branch is then carried out to identify the probable failure mechanism and then

Why 1		**Why 2**		**Why 3**		**Why 4**		**Why 5**	
Why are processing of jobs delayed?	There is no computerized solution to handle job applications.	**Why is there no computerized solution to handle job applications?**	There was staff resistance	**Why was there staff resistance?**	They were not explained the full benefits of the system	**Why were staff not explained the full benefits of the system?**	There was a lack of communication	**Why was there a lack of communication?**	We assumed that the benefits were obvious
					They feared being made redundant.	**Why did they fear being made redundant?**	They thought the computer system was designed to replace them	**Why did they think the computer system was designed to replace them?**	Because we didn't tell them how it would help make their jobs easier
					They were uncomfortable about changing the way they worked	**Why were they uncomfortable about changing the way they worked?**	They had always been doing it this way	**Why had they always been doing it this way?**	All the work was done manually prior
							The positive aspects of the change were not communicated	**Why were the positive aspects of the change not communicated?**	We assumed that the benefits were obvious
	There was no formal set of procedures to handle job requests, and procedures were passed on by mouth as opposed to being documented	**Why was there no formal set of procedures to handle job requests, and why were procedures were passed on by mouth as opposed to being documented?**	There was no system in place to do so.	**Why wasn't there a system in place to handle job requests?**	The company grew at an exponential rate that there was no time to document anything	**Why did the company grow at an exponential rate that there was no time to document anything?**	There was insufficient planning	**Why was there insufficient planning?**	Top management were too busy fire fighting and dealing with operational work, rather than developing a strategy

Figure 1 : A Typical Why-Why Analysis1
Courtesy: Cornell Management System for Safety, Health, and the Environment

to devise mitigation methods. This method is simple to draw and considers different consequences but also has the associated disadvantage of becoming complex as many branches evolve for the same tree. This method also does not show any changes as the fleet grows old.

c) Fault Tree Analysis – This method is used to create a model that helps in analyzing the failure mechanism of an engineering system. This involves creating a logical diagram which plots the series of faults leading to the failure of the subsystem or system (refer figure 2). This method involves assessment of failures due to component wear out, failure of materials to perform as desired, or malfunctions owing to various reasons. The analysis involves drawing the tree listing various failures.

d) Cause and Effect (Ishikawa Diagram) — The cause and effect analysis is a systematic way of generating and sorting hypotheses about possible causes of a problem. The method helps to identify the causes leading to the end effect and also in the classification of the causes into various categories such as people, process, equipment, and material (refer figure 3). A typical cause and effect diagram will start with the problem and then identifying what caused the problem(s). The causes so identified are then analyzed thoroughly using various other methods as mentioned earlier.

Subsequently, the ease-of-implementation vs. the impact matrix helps to prioritize the implementation of improvement actions – actions which are easy to implement and will provide high impact in resolving the problem go first, and the actions which are hard to implement and have a low or medium impact will be implemented later.

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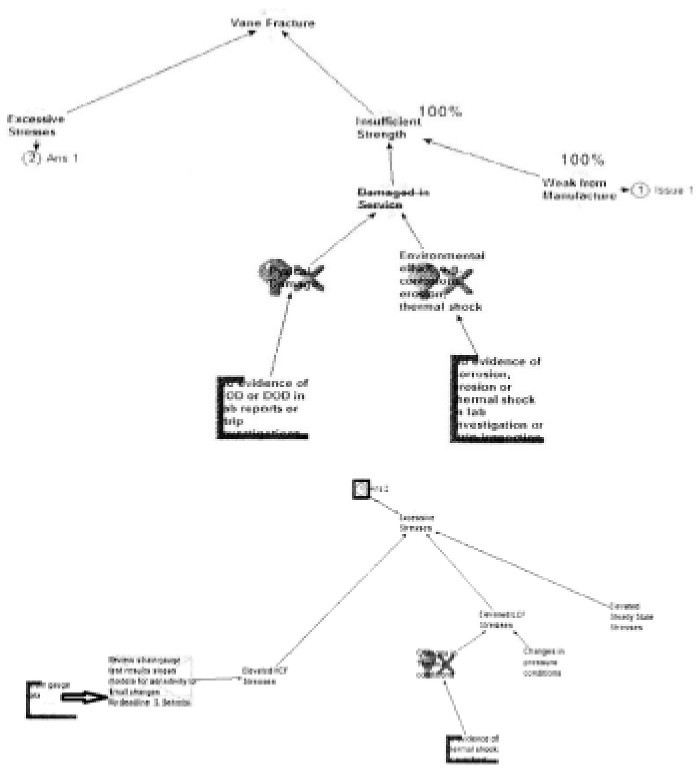

Figure 2 : Event / Fault Tree

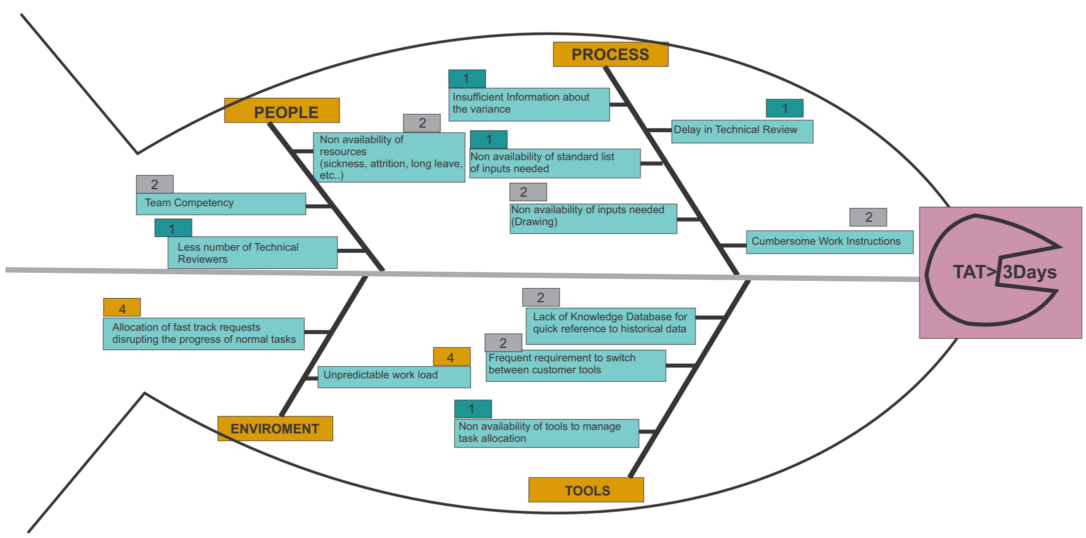

Figure 3 : Fish Bone Diagram

Identify and Implement Corrective Actions

Effective root cause identification will be useful in identifying the appropriate corrective actions. There can be multiple corrective actions required to address the problems effectively. The corrective actions are then further developed and tested in isolation and in combination. The corrective actions may involve design improvements, and process improvements. If the corrective actions involve design alterations, then development and testing may first be carried out using computer models, followed by testing prototypes on development vehicles. When sufficient successful development experience is gained, then live implementation of corrective actions is initiated. The in-field implementation of the improvement is also typically deployed initially into a part of the fleet. The implementation of the corrective actions is followed by data gathering to assess the results.

Preventive Actions

Post Successful implementation of the corrective action(s) in the affected fleet, the improvement actions may be deployed to similar equipment in other fleets preventing the events before they occur. However, the implementation of such preventive actions may involve tailoring of the methods and principles to suit the specific fleet conditions.

Case Study

Issue: Loss of engine performance indicated through Engine Health Monitoring (EHM) reports. An alert was raised to the operator to borescope the turbine section for any anomalies. Post borescope, turbine blades and nozzle guide vanes were found to be damaged. The engine was, therefore, removed from service.

Data Gathering and Categorization

Following parameters were gathered for the affected engine to analyze the event in detail:

a) The engine health reports — To validate the engine performance parameters
b) Previous shop visit report and recent line maintenance data
c) Event history — To identify any events related to the turbine failure, such as high Turbine Gas Temperature (TGT) for more than 5 seconds, high vibration, and surge.

Based on the initial findings and details collected from the field, the event was categorized as **basic** (engine related), **unplanned** (not as per the planned maintenance schedule), and **removal** (engine removed from service). The operator was then instructed to ship the engine to the overhaul shop for further repairs.

Data Analysis

The data collected post-categorization was keyed into the EM system. This data was analyzed to identify similar failures in the past within and across fleets of similar engines. The required data was extracted by eliminating the events not related to similar failures.

The shop visit report showed the primary and secondary findings of the damage. The findings indicated excessive rubbing of the seal segments with the turbine blade shrouds. Three instances of such events were recorded earlier in the fleet. However, this was the first instance of this engine and with only 600 hours since the last shop visit.

Given the data of the findings from the previous reports and feedback from the overhaul shop reports, the data was plotted onto a Pareto graph to understand the top drivers of such events. The top driver analysis yielded results to notify the top issue of failure as rubbing of the turbine blades with the sealing strip.

Root Cause Analysis

With the shop visit findings for the current engine and the details from the historic shop visit reports, 'Why-Why' approach was used to determine the possible scenario and understand the root cause.

The root cause from the historical and current

Why 1		Why 2		Why 3		Why 4	
Loss in Engine Performance?	Due to rubbing of the turbine blade with the seal segments	**Why did the turbine blades rub with the seal segments?**	The seal segments slipped from their position and sagged down	**Why did the seal segments sag?**	The seal segment locking tangs were worn	**Why did the wear occur on tangs?**	The tang was worn due to excessive thermal expansion and contraction

Figure 4 : Why-Why Analysis

evidence was determined to be the worn tang on the seal segments, which led to the contact with the outer shroud fins of the blade.

Corrective Action

The investigation into the failure mechanism led to the conclusion that there is a potential of the blade and the seal segment rubbing. Hence, as a containment action (to prevent failure until a permanent solution is introduced), a borescope inspection (to be repeated every 100 flight hours) in the turbine region was introduced to check sagging of the shroud segment and report the anomalies, if any, to the OEM.

The detailed problem investigation revealed that a design change is necessary. Hence a new design was introduced instructing to machine off the radial height (by few millimeters) of the abradable material to accommodate the wear criteria. This increased the diametral clearance marginally. The performance evaluation of the engine was conducted with the increase in the tip clearance. It was found to be affecting minimally without compromising the engine certification requirements.

Preventive Action

This is a recently introduced design change and is yet to be monitored for desired results in the affected fleet. If successful, the best practices may be deployed to other fleets with similar engines.

Emerging Trends

The EM process is used only in a few capital-intensive industries like the Aeronautics and the Aerospace, and by a very limited number of high-end automobile companies. However, there is a scope of taking this process into other industries like Home Appliances, Surface

Transportation. There is an increasing trend to offer extended warranties for various products in these sectors. The OEMs offering extended warranty for their products, own the maintenance and break-down support. To reduce break-down maintenance and escalating maintenance costs, alongside a growing customer demand for more reliable components, more and more industries are adopting EM.

The other major sectors where the EM can be implemented are:

- Home appliances (refrigerators, washing machines, televisions, and more)
- Safety and security systems (fire-fighting, closed-circuit cameras, access control system, and more)
- Telecommunication (reliability of the hardware and associated software, connectivity, and others)
- Trains and road transport (high-speed trains, and modernized buses)
- Power generation systems
- Software
- Healthcare
- Oil and gas exploration

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Summary

QuEST has a dedicated team of qualified engineers supporting EM and service investigation work streams for major aero engine and aero structure customers. Over the years, QuEST has built the capability for an end to end EM process. It includes data gathering, data maintenance, investigation, and representation of the findings as well as proposing the appropriate solutions for various types of events.

QuEST provides length and breadth of services all along the product life cycle right from the concept to the aftermarket support, and the retirement phase of the products. Therefore, the corrective or improvement actions identified during the EM processes are further taken up by the teams at QuEST for development, implementation, monitor, and control.

QuEST also has the proven capability to manage the cross-functional activities involving multiple stakeholders (e.g. OEM engineering

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teams, third party vendors, and multiple teams at QuEST). QuEST has demonstrated capabilities across verticals and customers. By offshoring this work-stream, customers can benefit from the rich experience and the well -established processes at QuEST without having to re-invent the wheel all over.

References

a) 5-whys Analysis using an Excel Spreadsheet Table
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Author Profile

Rajesh Kumar Handuja
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Rajesh is a specialist in Aftermarket Services for Aero Engines. He has extensive experience in supporting In-Service Products, Lifecycle Cost Analysis, and Managing Maintenance Burden.

Before joining QuEST in 2008, Rajesh was with the Indian Air Force for 20 years in various capacities. He holds a Bachelor's degree in Mechanical Engineering and has done his Master in Business Administration in Human Resource Development.

While with the Indian Air Force, he was involved in the on-wing and in-shop maintenance of aero engines. He developed the technical process for Fan Blade Replacement and in-storage preservation of various fuel aggregates for the aero engine of a Russian military aircraft used by the Indian Air Force. He was instrumental in setting up a medium repair facility.

At QuEST, Rajesh is a Technical Solutions Leader for service engineering and lifecycle engineering. He has vast experience in establishing work streams from scratch. His current responsibilities also include capability development and new business development. He is driving the Capability Led Growth initiative at QuEST.

He has also authored the following papers:

a) Opportunities to reduce Total Cost of Ownership in Aftermarket Services
b) Reliability Analysis and Emerging Trends

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