Aeronautics A4 Case Study

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The continuous advancements and improvements of manufacturing equipment and technology require constant reevaluation of best practices. Manufacturing facilities continually have to meet new standards and benchmarks in reliability, maintainability, safety, cost reduction, and environmental concerns, and every year these requirements are elevated creating a culture of accountability that demands improved performance. The need for new and improved RCM applications becomes critical as demands become greater. RCM is a proven methodology but not sustainable in the current business climate. LMCO (Lockheed-Martin) with the assistance of Eruditio developed and implemented a new best practice for maintenance.

Lockheed-Martin & Eruditio

Since 2017 Lockheed-Martin (LMCO) Aerospace Division Plant Engineering & Integration (PE&I) has partnered with Eruditio LLC to address their business needs. PE&I developed and launched the A4 initiative (Assurance, Availability, Affordability & Accountability) across three aerospace manufacturing sites: Fort Worth, TX, primary and final assembly facility for F-35; Marietta, GA, multi-aircraft and subassembly facility which produces the C-130; and Palmdale, CA, manufacturing and R&D site and home of Skunkworks. The A4 tactical framework centers around the use of customized RCM techniques developed by Eruditio LLC to deliver on the four As.

In the past twelve months, these new techniques have been applied across all three LMCO Aerospace manufacturing sites to develop Equipment Maintenance Plans (EMP) for hundreds of critical assets.

In March 2017 Rob Sacket, PE&I Enterprise Senior Manager and Scott Kelley, PE&I Enterprise Manager, began developing the A4 framework and their vision for the PE&I department. This marked the beginning of A4 with an objective of evolving from a reactive to a proactive and predictive maintenance organization.

Assurance/Availability

Across the division Rob Sackett saw the maintenance team's reliance on "tribal knowledge", or informal practices developed over years of on the job experience as an issue with severe consequences in the immediate future. The workforce was entrenched in a reactive maintenance environment. Operations were run-to-failure and reliant on "cowboying repairs and diving catches". Predictive maintenance was not part of the group conscience.

Technicians that could quickly restore a down asset to service were heroes. Technicians that maintained equipment through precision maintenance and prevented failures and the introduction of defects were unheralded. This culture reinforced reactive maintenance practices and philosophies. By March 2017 Aero PE&I became fully aware that to achieve asset assurance and 85% asset utilization as laid out in the A4 plan, they would not only have to change practices but also change culture. They needed to cultivate a maintenance culture that embodied the first two As of Assurance and Accountability.

Assurance

CURRENT		FUTURE
Assets Hierarchy		
High-level grouping assets by plant geography	Assets grouped by functional parent-child relationships.	Asset hierarchy includes B.O.M. attribute and historical data.
Critical Equipment Risk Ranking (CERR)		
"Critically" is perception-based. No formal risk analysis.	System-level risk rankings illustrate improvement priorities.	Critically is used to make strategic asset management decisions.
Equipment Maintenance Plans (EMP)		
Time-based PM routines are in place based on OEM recommendations.	Failure Codes are used to evaluate PM effectiveness.	EMP is failure-mode based, driving >70% of CM work generation.
Bill of Materials (BOM)		
Some BOM's exist but are inaccurate and rarely updated.	Bill of Materials exist for critical spares using A-B-C classifications.	100% of critical assets use BOM to identify & order spares.
Compatibility Management Plans		
Skills training by role, managed via Learning Management System.	Training mapped to critical tasks and evaluates application.	Skills training supports EMP, based on SWI's, routinely reviewed.

Figure 1 - LMCO Assurance current/future state assessment

Availability

CURRENT		FUTURE
Asset Health Management		
Sensor data collection for critical systems. Not failure mode specific.	Condition monitoring trends used to identify corrective actions.	Asset data is routinely reported. Known defects corrected in < 20 days.
Root Cause Analysis		
Some RCA on high-severity failures. RCA is informal and ad hoc.	Engineers, Supervisors and Technicians trained on RCA methods.	RCA triggers align to business objectives. Formal process exists.
Work Order Prioritization		
Work order priorities are subjective, based on perceived "criticality".	All "critical" systems are ranked using CERR analysis.	Criticality and defect severity drive 100% of work order priorities.
Maintenance Backlog Management		
Daily coordination relies on individual job skill and experience.	Formal planning and kitting processes exist to reduce downtime.	"Ready" backlog drives schedule. < 10% Reactive maintenance.
Reliability, Availability, Maintainability Modeling (RAM)		
Undefined reliability & maintainability MOC parameters.	Capital process includes reliability & maintainability gates.	RAM used to validate design, operating & maintenance changes.

Figure 2 - LMCO Availability current/future state assessment

Affordability

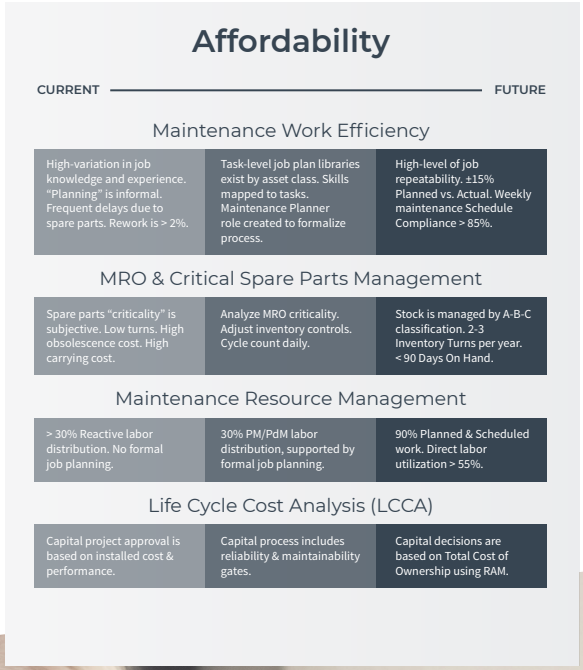
The market downturn in 2008 affected manufacturing dramatically. For the first time in years, maintenance and budgets across the industry were drastically reduced. At LMCO maintenance departments were required to do more with less and this trend continues despite any amount of economic recovery. As a result, maintenance practices within LMCO are continually evolving. Steve Ehrlicher, Director of PE&I, in an address to the A4 Senior Leader Team (SLT), confirmed the existence of these demands and the need for an A4 cultural change initiative stating;

> "Within Facilities and Plant Engineering our A4 initiative will proactively position us to continue improving processes to ensure site and program readiness."

The marching orders were clear; eliminate waste and inefficiency, embrace innovation, and give operations the ability to produce.

To do this the A4 team is focused on maintaining a balanced work distribution of planned inspections and corrective maintenance, and emergent work. It is a common belief in the maintenance and reliability profession that unplanned work is six times more expensive than planned work. A primary objective of the A4 program is for the "right work to be done at the right time by the right people". Maintenance is planned deliberate, and precise.

Figure 3 - LMCO Affordability current/future state assessment



Accountability

You cannot hold people accountable without a standard for performance. This was the general sentiment of Rob Sackett and Scott Kelley as they developed the A4 framework. Rob stated "Maintenance Technicians knew their jobs but they didn't understand the mission". Good work was being done but it was only enough to keep things moving. The A4 team realized that to deliver their vision everyone must be held accountable to the A4 standard.

The PE&I team looked to established asset management standards such as PAS-55 and ISO 55000. They travelled the country observing maintenance best practices and benchmarking world class organizations from a variety of industries. The team realized a need for a complete maintenance overhaul and inclusion of RCM processes.

Using the RCM asset management framework, they developed practices and procedures requiring engineers, technicians, and operators to manage assets in concert with one another and provide accurate failure data. When analyzed, the collected data would allow for intelligent business decisions. The need for improved communication became one of the cornerstones of A4. Prior to A4, failure data was rarely recorded or shared and the information that did make it to the engineers was unreliable.

In 2014 LMCO Aero manufacturing facilities began using a catalog of 93,000 error codes for recording of asset failures into the Enterprise Asset Management System (EAM). The failure codes were designed to provide information for the Failure Reporting Analysis and Corrective Actions System (FRACAS). Reliability engineers and other stakeholders use FRACAS to analyze failure data and track corrective actions to manage change and eliminate defects. The volume of codes and the difficulty in selecting and entering one made failure data entry unrealistic. Ninety-three thousand (93,000) failure codes had to be individually searched in hard copy leading to 98% of all entries being "Code 999" or reason unknown. It became a "garbage in, garbage out" scenario. Over five years not a single error code report was run from the system. The data offered no analytical value.

PE&I had invested in recording failure data. There were engineers on staff to conduct analysis and floor personnel able and willing to record data. However, none of this was being done and no one was held accountable. One of the primary A4 targets is failure code development and utilization. Rob and his team, with the help of Eruditio, have engineered out the obstacles that prevented techs and operators from entering information and established reliability leads at each site required to analyze failure data.

Phase I Foundational Elements, System Selection

Phase I aligns with the first four steps of the RCM model, but due to the absence of reliable data, deviations from standard RCM practice were made. Considerations were given to capture the collective opinion of criticality from various stakeholders, rather than data.. Production operations (ProdOps) had great influence, but all stakeholders were engaged. This is critical to achieving a balanced result that can attain buy-in from everyone involved. Selection of systems was a collaborative decision.

Critical Equipment Risk Ranking (CERR) Tool

Lockheed Martin | Fort Worth | F-35 Manufacturing

	Capability	Reliability	Maintainability
Insufficient risk controls. Re-engineer asset to eliminate failure modes.	HIGH 10%	HIGH 2%	HIGH 6%
Sufficient risk controls. Monitor and trend asset health conditions.	MEDIUM 21%	MEDIUM 8%	MEDIUM 37%
Sufficient risk controls. Look for opportunities to optimize cost.	LOW 70%	LOW 90%	LOW 57%

9/4/2019

Asset Description	Functional Failure (e.g. PREDOMINENT FAILURE MODE)	OPS	ES&H	COST	CONSEQUENCE RISK	MTBF	PROBABILITY RISK	ECA	CONDITION BASED RISK
175 Robot	UNABLE TO COAT PLANE within finish tolerances.	10	8	9	54.0	7	378.0	7	2646
234 Robot	UNABLE TO COAT PARTS at a rate of 8 carts per run.	10	8	9	54.0	10	540.0	6	3240
DURR Line	UNABLE TO TRANSPORT PARTS between stations.	7	5	7	38.0	8	304.0	6	1824
AutoDrill	UNABLE TO DRILL holes in structure at the desired rate.	10	8	9	62.0	8	496.0	6	2976
FOG Mill	UNABLE TO MILL parts at the desired rate.	8	8	9	58.0	9	522.0	4	2088
EMAS	UNABLE TO MATE airframe within engineering tolerances.	2	8	6	32.0	9	288.0	4	1152

Figure 4 - Example of the LMCO criticality tool.

Once the A4 team identified critical systems, critical assets were identified using a criticality and risk assessment tool developed by Darrin Wikoff, Scott Kelley, and Zach Solis (LMCO Enterprise Reliability Engineer). The tool considers operational, safety, environment, and maintenance impacts of asset failure. It considers asset condition on a 1-10 scale from “Brand-New to Unusable”. In the absence of good data associated with the assets, this gave the PE&I team insight into the condition of the equipment and impacted its candidacy for RCM. An asset can be critical with a run-to-failure maintenance strategy due to age. It would be an inefficient use of resources to conduct RCM on these assets. For this reason, the team added machine condition to their criticality and risk assessment.

Phase I Foundational Elements, FMEA

Accurate FMEAs are critical for LMCO. They have one of a kind assets that are designed and exist solely for the function of producing specific aircraft. This makes the accurate execution of a FMEA critical. There is no historical data on much of the equipment. Work order histories lacked sufficient detail to quantify the frequency of failures at the component level. Knowledge of component failure modes resided in tribal forums, undocumented due to the difficulties caused by 93,000 failure codes that diluted any valuation of failure modes and their effects. What is captured during the FMEA event is the only source of information provided to engineers and maintenance personnel to develop an EMP. It is the medium used for creating failure codes in the

A4 process. Darrin Wikoff created a method for developing failure modes for entry into an EAM as failure codes. The approach blends empirical data by asset classification and experiential data provided by Aero personnel, focused on the commonality of both data sets as an as-is picture of failure modes probability. These failure codes are created by a team of experts during the FMEA process. This begins with the creation of a Functional Block Diagram (FBD) down to the subsystem level. The team then identifies components down to the lowest maintainable level with the assistance of the hierarchy developed during an equipment walkdown. This is where Wikoff's method deviates from a typical classic or RCM deviation. In the Wikoff method, the asset class is identified as the lowest maintainable item. For example, all centrifugal pumps fail in the same ways. "A pump is a pump is a pump", is Wikoff's view. Pumps don't care where they live. The failure mode exceptions to this belief are operation contextual and are captured by the SMEs.

This philosophy has been applied to large assets at LMCO during A4. For instance, LMCO has autoclaves at all three manufacturing sites. The autoclave FMEA was conducted at the Fort Worth facility as one single asset. That FMEA and the results have been applied across aerospace successfully. Given a similar operating context, autoclave failure modes do not change so neither does the maintenance strategy.

Once FMEAs are completed for all critical assets, the identified failure modes are converted into failure codes for use in the EAM. This is part of the FRACAS aimed at capturing failure data immediately following a breakdown. By design, a user-friendly hierarchy is put into the EAM and consists of cascading drop down-boxes expediting the entry of failure modes and reduces risk of error by guiding the user to one specific part, problem, and cause within 5-8 categories with 4-8 possible entries in each drop down-box. The typical process moves down the hierarchy from;

System
Subsystem
Asset
Component (Part)

Problem
Cause
Corrective Action

Depending on the complexity of the system, the amount of entries needed to identify a failure mode varies. However, Lockheed Martin conducted a study and found that it takes an untrained employee 19 seconds on average to enter a failure code in the system. This use of failure codes satisfies one of A4's main objectives of capturing accurate data for analysis.

> "Simplifying the collection of failure codes accelerates Aero's ability to quickly refine failure mode analysis and adjust equipment maintenance."

RESULTS

The initiative is on-going and confirmed results to metrics such as Overall Equipment Effectiveness will take time to be realized. We can measure the effects of Phase I. In figure 5 you can see the number of preventive maintenance tasks changed in each category during a recent PMO exercise at the Palmdale, CA site. Through the RCM process, the total amount of maintenance being conducted

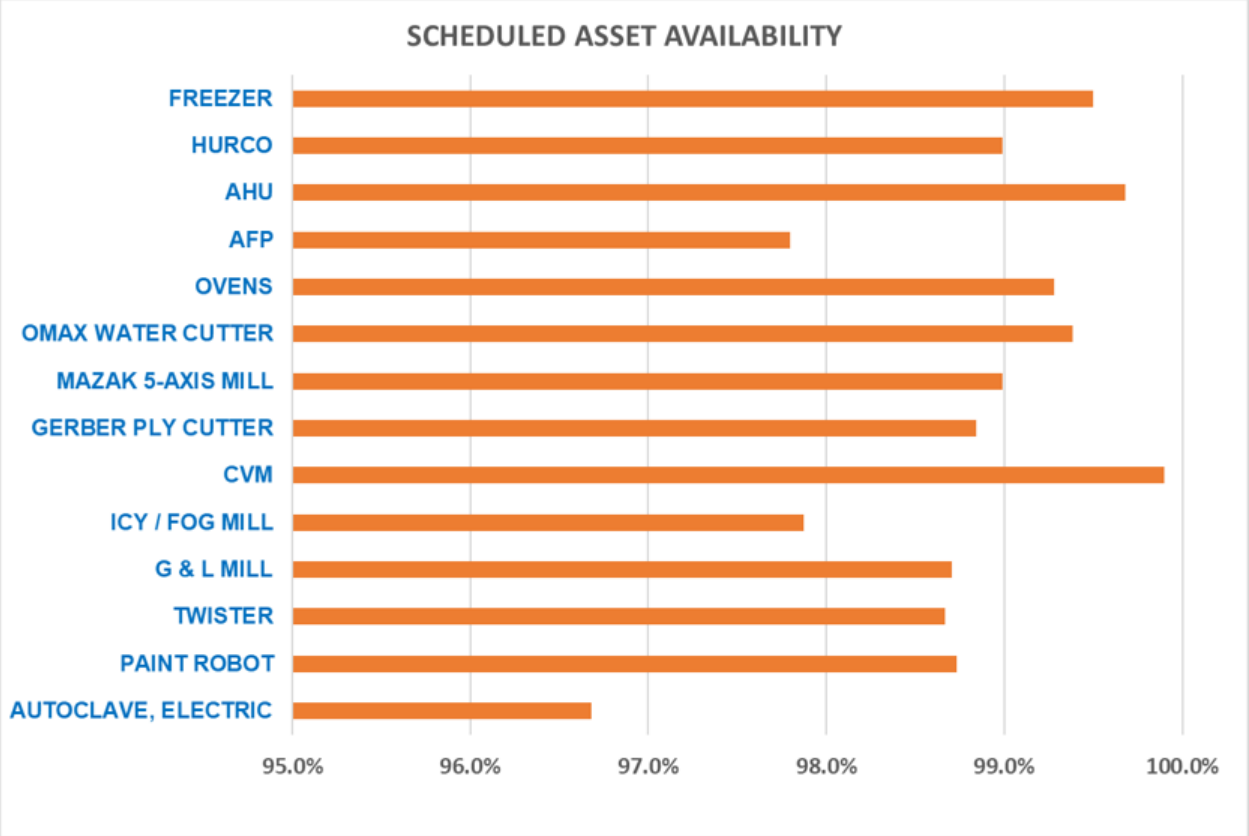


Figure 5 - Maintenance plan evaluation

increased from 153 to 191 hours. This was not from increasing head count but using operators in routine maintenance, the expansion of non-destructive testing, and additional run-time preventive maintenance. Tasks that did not align with the EMP or contribute to reliability were eliminated. The FMEA and EMP provided criteria to measure maintenance task effectiveness. Preventive and predictive maintenance coverage increased by 263% on average, with a 66% decrease in labor hours per asset.

Due to the expeditious nature and the RCM techniques facilitated by Eruditio, FMEAs have been completed for all 211 critical assets across Lockheed Martin Aerospace, developing risk-based equipment maintenance plans for nearly 55,000 unique assets. Conducting the FMEA down to the asset class level has allowed for this. In two months, Eruditio was able to create PM programs for 37 asset classes at the Palmdale, CA facility. This in combination with the use of the CMMS by technicians and operators to report failure data for analysis has provided LMCO Reliability Engineers with the ability to apply their Critical Equipment and Risk Ranking (CERR) tool. Failure mode entry can be done in 19 seconds. The program regularly improves itself by adding evaluated asset classes and continuously providing quality failure data.