Fundamentals of Sustainment: Affordable Observation and Assessment

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This paper provides a 5-step approach for an *effective* and *affordable* assessment program for your space-based enterprise. In the Complex System Sustainment Management Model, defined in previous papers by the author, observations lead to risk identification and system fixes to mitigate those risks. Risks cannot be identified and mitigated unless the weapon system is sufficiently observed so that data and analysis can point to future degradations of the weapon system. If the assessment program used to observe the system is not *effective*, the organization has potentially system-ending blind spots. In addition, if the assessment program is not *affordable*, the inevitable cutbacks will also, eventually, kill the system. The paper concludes with an explanation of how the enablers of people, process, and IT support affordable observation.

I. Introduction

The complex system sustainment management model[1] is "observe, identify, and fix". Figure 1 denotes the weapon system version, but it can be generalized to any complex system, including space systems.[2] The activities in the "Fix System" box include long-range planning, short term planning, deployment planning, requesting funding, and flowing funding to programs and projects. Decision-makers need this information to grant funding. The raw data needed to create this information comes from identifying risks to the weapon system mission with sufficient lead time to get them fixed. Risk are written against the readiness factors such as reliability or accuracy. Risks cannot be identified unless the weapon system is sufficiently observed so that data and analysis can point to future degradations of the weapon system. For instance, monitoring batteries in the ground launch system can predict when replacement will be needed with more precision than a manufacturer's stated life. Warfighter requirements, such as probability of target destruction, are used to derive the readiness factors (accuracy, reliability). And these readiness factors directly impact how sustainment risks are written. The model is useful as a common language and a means to create and improve formal processes.

Also discussed were the important enablers of people committed to the mission, ever-improving process discipline, and responsive IT teams.

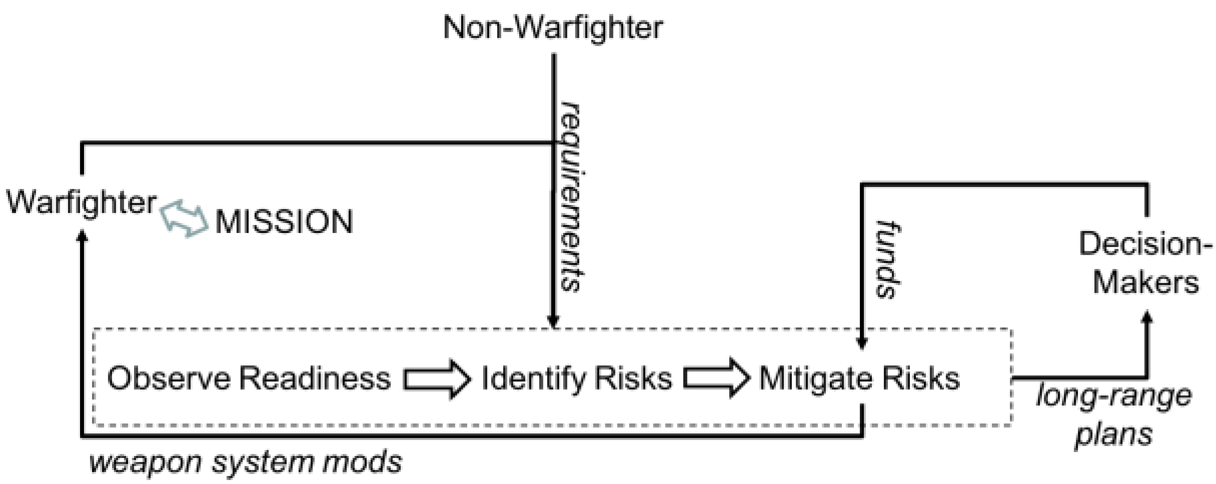

Figure 1: The Complex System Sustainment Management Model

The place to start when incorporating this model is "identify risk" since it immediately touches all other parts of the model[3]. But the next most important place to expend effort, and the subject of this paper, is "observe readiness".

Any effective sustainment organization has a method to view the system it is responsible for, and to assess its effectiveness. In the model, this directly feeds the identification of risks to the readiness of the system to support the mission.

If the assessment program is not effective, the organization has potentially system-ending blind spots. If the assessment program is not affordable, the inevitable cutbacks will also, eventually, kill the system.

This paper provides a 5-step approach for an effective and affordable assessment program.

1. Use your “free” data
2. Look to your repair depots
3. Set up an age surveillance program
4. Establish processes for special testing
5. Analyze your data to create information

II. Use Your “Free” Data

Every employed system generates some amount of data. Discover that data and ensure it is making its way to your assessment team. There will, of course, be some costs associated with this action, but less costs than if you had to create the data yourself. Before rejecting it for cost, consider the costs of not seeking out and creating a pipeline to this data.

Are there portions of your system that are running some or most of the time? Is this data streaming into someone’s network already? Which parts of your system are inert (you’ll need to know this for a later step)? Do these inert parts create any data inadvertently? For instance, you may have data on how often a component is stocked and switched out during periodic inspection.

Some examples of “free data” are measurements taken within the system while operating, parts availability rates, bench stock depletion rates, failure rates, and repair depot testing.

When getting your team access to this data, ask them the best ways they know to collect and filter it. Like all the data collected on your system, certain rules apply:

a) If you collect it into more than one information management system, the data on one system will diverge from the data on the other system and create headaches for analysts. If you must keep it in more than one place, create a way to reconcile it.
b) Your team needs this and other data. They don’t know how they will use it in the future because a good team is always improving. In addition, great data tools will lead to better team processes which will lead to needed changes in data tools. So, give your team the tools to continuously improve their information management systems. See figure 2.
c) Meta data telling you about the data you have collected may be just as important as the data. Where did it come from? What are the errors common to the data? Should your statisticians expect a normal distribution or some other distribution? Is it prone to artifacts or outliers? Will sources remain consistent over time or will untruthful trends sneak into your analyses due to drifting factors unrelated to the underlying system? For example, something as innocuous as changing techniques for recording the data can lead to inconsistencies from year to year.
d) Does the data come from machines or people? If people, are they motivated to enter the data correctly? Data entry people such as repair depot technicians can be given a stake in creating good assessment. For instance, better repair diagnostics.

Why do to all this trouble? Besides the obvious economical aspects, it will save considerable embarrassment when those in the know contradict your analyses and your request for funds with commonly available information. A critic might say: “You say you need a new fuel depot interlock, but your LEO refueling rates are currently outstanding.” You should be able to say: “The overall trend shows that within the time span of building the new tester, our rate will sink to well below acceptable limits. In addition, we have recently lost potential new customers to providers with better rates.”

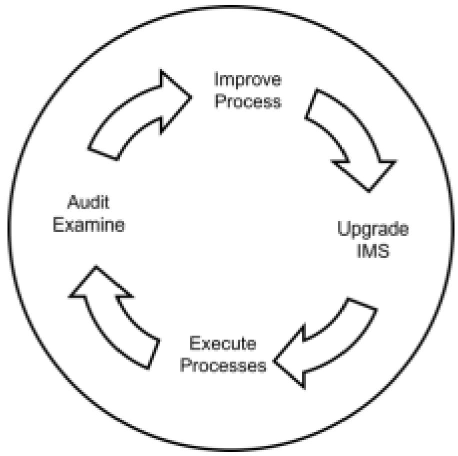

Figure 2: The Process Improvement Cycle Requires Timely IT Tool Updates

III. <u>Look to Your Repair Depots</u>

Repair shops, depots, and other similar facilities are often created and run by organizations purposefully focused on productivity and throughput in order to ensure economical repairs. A great example of this tendency is the Air Force Sustainment Center “Art of the Possible” e-book[4] which is replete with ways to ensure economical production via speed. (example: “Chapter 1 Introduction: The Value of Speed”) This is exactly what the Sustainment Center should be doing, saving tax dollars via efficient production.

However, if you are not careful, this approach can be sub-optimal to your goals of observing your system to identify and mitigate risks with sufficient lead time. For example, they may be focused on rapid remove and replace processes where the original failure can be lost in the shuffle. See figure 3. Therefore, your sustainment organization will need to contract with your repair depots to ensure you get the data you need, when you need it. The best scheme for this is the Closed Loop Failure Analysis (CLFA) program.

CLFA is MIL-HDBK-2155 FRACAS (Failure Reporting and Corrective Action System) employed at a repair depot. FRACAS is designed to discover problems during production by finding unforeseen failure modes. It can be used very effectively to find new emerging failure modes during the sustainment phase.

CLFA seeks to "close the loop" between the failure noted and the repair made. In its most basic form, it does this by asking the question in the top left of the graphic above: “Did this bad part create this fielded failure?”

An affordable repair depot works to increase throughput while keeping costs down. Diagnosis is performed to the extent needed to ensure a repair. Large depots can contain many shops that perform their work somewhat independently of each other. A subsystem might be delivered to the depot and have a component removed and replaced and the subsystem is tested and sent out again. Meanwhile, the component may have a part removed and replaced and then the component is tested and placed on a shelf as a good spare.

This remove and replace strategy is a good one for speed, throughput, and affordable repair. It will certainly be the model used for in-orbit depot repairs. It has the potential to allow failed parts or components to remain in service and for emerging failure modes (those not thought of during design) to remain undetected.

Good sustainment organizations will enter into agreements with their depots to ensure repairs are traced back to failures and sufficient diagnostics are performed to ensure emerging failure modes are found. This sounds expensive, but even if the program starts with 100% screening, it can quickly eliminate from scrutiny those failure modes and repairs that are well known or become well known after CLFA has functioned for a few years.

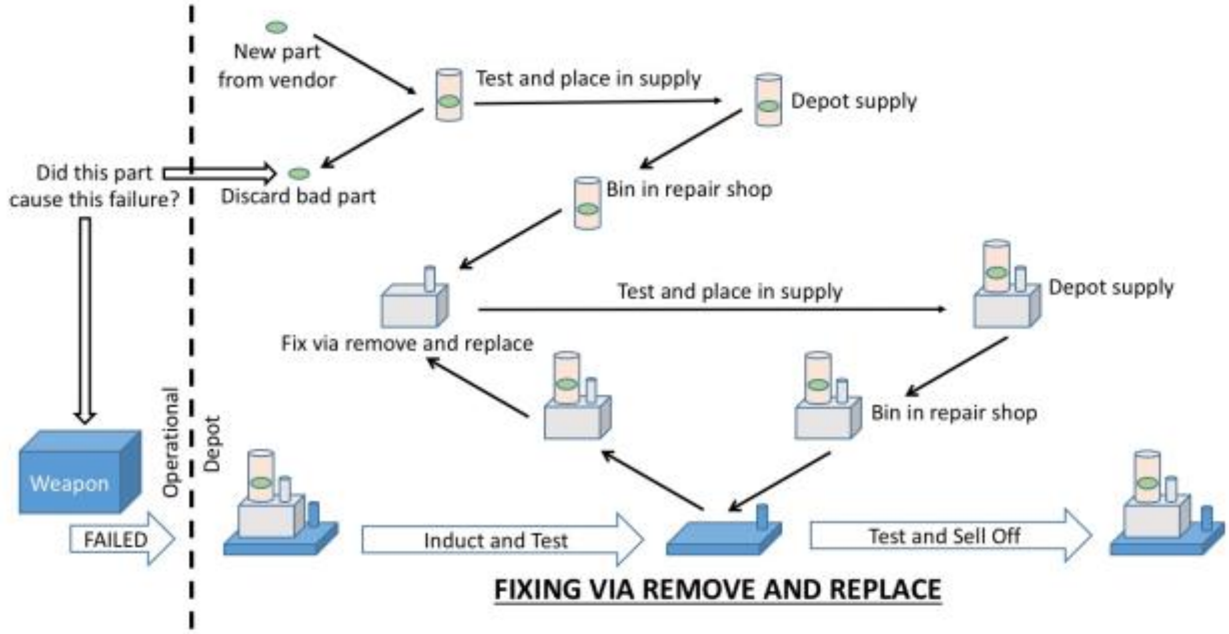

Figure 3: Remove and Replace Depot Repair

Having proven itself, a mature CLFA program will not limit its investigations to only system operational failures. Subsystems and components can and do fail in the depot and elsewhere, revealing important system assessment data. In addition, a mature CLFA program will also take the findings of its failure review board and use them to improve its own depot processes and equipment.

CLFA demands good processes and a good information management system to handle the large amounts of data generated and analyzed. In-orbit repair depots will depend heavily on AI algorithms. Ensure those algorithms capture the data you need.

There is also a clear benefit to the repair depot. More intense tracking will prevent poor components from circulating in orbit between customers and the depot. This happens nowadays on Earth when new emerging intermittent faults combine with outdated diagnostic and final testing. This leads to "bad actor" systems being released to the field, often, but not always, the same serialized box. The possibility of this "bad actor" syndrome should be considered when failures of a particular subsystem begin to increase.

IV. Set Up an Age Surveillance Program

What are your on-orbit and terrestrial systems' failure modes? How will they wear out? Are there parts that will age out? Some of this information comes from design data, other comes from use, maintenance, and repair data -- if you are paying attention. A surveillance program can be built around this data in order to track degradation and predict future issues.

Some parts of your system will be akin to light bulbs in that their failure is obvious and the failure mode is well understood. Other parts of the system remain inert until needed. Your reliability readiness factor will dictate how often a failure is allowed upon activation.

But how do you anticipate a downward trend in that failure mode if that part of your system is not exercised often enough to provide the trend? That subsystem is analyzed for expected failure modes. Those modes are analyzed to predict their symptoms, and representative subsystems are exercised often enough to look for these symptoms and detect any trends.

For instance, a global near space internet connection system is operated from balloons. A back up system must operate to protect the electronics in case of electrical events such as lightning, auroras, or cosmic rays. These incidents are so low that these systems are hardly ever activated. Will they operate at the needed 99% reliability?

The solution: Systems are taken from balloons as they cycle and are kept in chambers to simulate more cycles. In these chambers, they are activated regularly to collect data. The monitoring equipment has been designed with the expected failure modes in mind to capture the expected symptoms. To protect against surprises, systems are occasionally removed and completely disassembled and components are tested, looking for unexpected and new emerging failure modes.

Another example: an LEO space tug could have certain modular parts manufactured in enough numbers to keep a few on Earth in simulated environments to help determine types of failure modes with lead time for replacement modules to be available in orbiting warehouses.

V. Establish Processes for Special Testing

There will always be the need for special tests. These tests will deal with gaps in your knowledge that start to become apparent as all the other data is analyzed and compared to your system readiness factors.

For instance, statistics indicate that fuel is being lost by your LEO transport tugs somewhere after it is generated and loaded on the tug, and before it is delivered to the customer. Current monitoring systems indicate no fuel loss at initial loading or at off-loading. A special test is designed and carried out to see if fuel can be lost in actuality at either of these points and still have sensors indicate no loss.

Key skills to cultivate in your sustainment organization are test plan authors and testing leads. Authors must be able to create test plans that focus on the information required, use methods that are unassailable, and proceed similar enough to previous tests to allow for test data points to be combined. Changes from one test to another must be thoroughly documented. Test plans must be vetted with the community and the decision-makers so that when test results arrive they do not reside outside the bounds of expectations and can be immediately understood by all, inside and outside the circle of experts.

For instance, the destruction of a solid rocket motor during testing might be viewed as a disaster by a CEO and Directors if no one told them ahead of time that the test was “to destruction” to establish an upper limit. And if the CEO fielded a question from the media before the full story was understood, things only get worse for all concerned.

Testing leads must rule the test with an iron hand so that there is no doubt that the test plan was religiously observed and deviations were thoroughly documented. All results must be recorded, especially those unexpected. For instance, a squibbed battery was tested in lots of 10. The third lot-of-10 was on its way to test before a technician casually mentioned the “odd yellow dust” near the piston assembly on “2 or 3” of the first lot. This was a symptom of an unexpected failure mode that was not specifically being tested. The third lot was delayed to rewrite the test plan to include this new knowledge. All old test items were re-inspected.

VI. Analyze Your Data to Create Information

For analysis, the best approaches to effective and economical observation are focused on “doing it right the first time”. If not, reporting the resulting information to your supervisors and decision-makers turns into multiple embarrassing personal training sessions. Areas most likely to go wrong are your inability to convey the trend, why the trend is important, why you think it is real, and why it needs to be identified immediately, or someday soon, as a risk.

Many people with many skills are needed to provide effective and economical observation. Three roles must be done well to succeed in analysis and reporting: the statistician, the engineer, and the person chosen to communicate with the sustainment organization. The statistician must be competent and comfortable with a wide range of options for modeling what the engineer believes is happening. A competent statistician will balk at the idea of using mathematics trends to forecast the future. The engineer must have the competence to observe the system and conclude what wear or age process is at work to create the symptoms observed. What new emerging failure mode is this? Together, they can create the model that displays the trend and the engineer can explain why and in what manner it would continue into the future. The communicator must be able to relay all this, especially to the decision-makers, along with why the particular mathematical model is best in this instance.

Good decision-makers know that no model is perfect, systems are hard to observe, and mistakes are easily made. Reporting needs to convey an understanding of this uncertainty and what, if anything, can be done to decrease it.

One method is double-checking between different kinds of observations. If a set of factory battery tests predict 50% reliability for 10-year-old batteries, yet 9 rockets have flown with 10-year-old batteries with no failures, perhaps the factory tests need some improvements.

Good observations depend heavily upon excellent configuration tracking. How can you really know what your system is doing if you have an errant component? Perhaps an early production lot of gyroscopes consistently creates problems. Solutions will be elusive if you don't recognize the problem is limited to only those few gyros.

Other sources of error include poor test plans, ineffective test directors, changing test conditions from year to year, more than one emerging failure mode confused as one, and locked-in thinking that uses data to confirm a strongly held belief.

Some errors are baked into the process. A good sustainment organization is always looking for ways to improve its processes. Your system will be constantly changing over time as new failure modes emerge, operators come to expect capabilities you didn't expect, and the world changes around you. Your organization's processes must keep up.

Step one in this activity is to periodically recheck your assessment program to see if it is looking at your entire system, looking at sufficient subsystems to ensure lead times, learning from new techniques from other assessment programs and doing all of this across the spectrum of the readiness factors that your operators or warfighters need to complete their mission.

Before you ever started this path of creating and executing an adequate assessment program, your organization should have reinvigorated its risk identification system. In this process, readiness factors important to the mission, such as reliability and survivability should have been defined. The best understanding of these readiness factors is always improving and should be a part of your periodic re-assessment of your assessment program.

Completing the circle, any deficiencies discovered in your assessment program should be written up as risks identified and discussed at your risk identification meetings.

VII. In Conclusion

In closing, and as mentioned in the introduction, it should be remembered that enablers of people, process, and IT are important to the successful execution of economical assessment. Your team's understanding of mission, system, and readiness factors must be combined with a willingness to speak up when data shows problems. They must also not only faithfully follow their processes, but speak up when the processes fail them. The organizational structure shouldn't be based on how it has always been done, getting a person a promoted, or other goals not associated with keeping the system sustained. It should place people together to share the skills needed in a task, retain skills that are scarce and easily lost, and encourage communication. The process audit system must be focused on the procedures and how to improve them and NOT be focused on punishing a lack of compliance. Finally, it bears repeating that computerized tools to hold big data and analyze it must be on a maintenance schedule associated with the process improvements and not arbitrary funding cycles.

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[1] Vono, Charles, "Fundamentals of Weapon System Sustainment", AIAA SciTech 2016, January 2016
[2] Vono, Charles and Kugler, Justin "Application of a Weapon System Sustainment Model to the Space Industry" AIAA SPACE 2016, September 2016
[3] Vono, Charles, "First Steps in Implementing Weapon System Sustainment Model" AIAA SciTech 2017, January 2017
[4] "Art of the Possible", 367TRSS.Hill.AF.Mil, 20 July 2015