Application of a Weapon System Sustainment Model to the Space Industry

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The Space Industry is moving steadily to longer-lived systems and more and more reusable components which triggers a greater need for an intentional approach to complex system sustainment. Thus, it is relevant to review how long-used weapon system sustainment practices can be applied to this Industry. The management model described in this paper, and first presented at SciTech 2016, is based on decades of sustaining the extremely complex Intercontinental Ballistic Missile weapon system. The model goes beyond logistics, supply, repair, and other piecemeal components of sustainment to provide a comprehensive and integrated approach. The model ensures success of the mission, deals with constraints of funding, and even accounts for unexpected requirements not associated with the mission. The model provides a method to generate the information needed to create short and long term plans. This information is the basis to tailor packages for industry partners, existing clients, potential customers, go-fund-me campaigns, tax incentive programs, and any other funds sources. The model also provides the best approach for sustainment risk management and the complex system observations that feed risk identification. Repair facilities will start to increase exponentially and must also be managed. The best ways to execute this model using disciplined processes, motivated people, and effective tech are also discussed.

Nomenclature

CSSMS	=	Complex System Sustainment Management System
FRACAS	=	Failure Reporting, Analysis and Corrective Action System
ICBM	=	Intercontinental Ballistic Missile
IoT	=	Internet of Things
IPT	=	Integrated Product Team
WSSMS	=	Weapon System Sustainment Management System

I. Introduction

SUSTAINMENT managers and their teams need a comprehensive yet simple management model that describes the core activities they must perform for effective and affordable management of their complex systems. Proliferation of very complex systems outside military weapon systems is a relatively new phenomenon so such management model exists at this time. This paper presents such a model and explains it in terms of its application to one such emerging complex, sustainable system: Commercial Space.

Vono's paper[1], presented at the AIAA SciTech 2016, described the method used to keep ICBMs a viable deterrent. This paper suggested that the model could be applied not only to any weapon system, but to any complex system requiring sustainment. (Non-complex systems would not necessarily require this rigor and discipline.)

Adoption of this model is a clear next-step in the evolution of complex systems. The need for, and creation of, the ICBM sustainment management model was a natural progression from the Industrial Revolution of the 19th century. The Industrial Revolution was embraced by militaries seeking an advantage in the battlefield. The Civil

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War, for instance, used trains, reconnaissance balloons, and underwater vehicles among other industrial age inventions to good advantage. However, none of these systems were highly complex and few (for instance, the surviving transportation infrastructure) were expected to be in use for decades after the war.

In the 20th century, weapon systems of greater complexity emerged, reaching a peak of development in the WWII years and immediately thereafter. Probably the most complex system developed was created in the early years of the post-WWII cold war era: Vast acreage of nuclear-tipped Intercontinental Ballistic Missiles (ICBMs). At their height, thousands of ICBMs remained moments away from launch to provide a credible to detterent to adversarial countries. In the current Minuteman ICBM system, each underground control capsule monitors and commands 10 underground launch sites equipped with sophisticated monitoring and controlling systems for the associated missiles. Support facilities and engineering sites located across the USA still keep the systems viable. In the last quarter of the 20th century, as once plentiful funds became increasing scarce and ICBM system lifetimes stretched out into decades, the USAF and their contractors became better and better at economical sustainment. And from this, the sustainment management model discussed in this paper came about.

Continuing into the 21st century, the trend for complex weapon systems to remain in service continues. And this trend has expanded into non-military systems. The USAF just released its vision for the next generation ICBMs, and they expect this new weapon system to last from 2020 to 2075.[2] Nonmilitary examples include Internet of Things (IoT) designs for huge factories, near-space airborne system in development to provide world-wide internet, and commercial space ventures. On 24 June, Vono led a seminar at the Utah Internet of Things conference in Provo (sponsored by the BYU Office of the CIO) where discussions focused on how the Sustainment Management Model discussed in this paper fits the current IoT industry. The highly secretive Google loon and Facebook unmanned aerial vehicles appear poised to go into full rate production soon in order to cover the globe with internet service.[3] This paper addresses the third example, Commercial Space.

Will Commercial Space complex systems follow a similar pattern of decades of use? AFSPC Commander Gen. John Hyten said in a recent interview with *Air Force Magazine:* If it takes 10 years to develop a satellite that lasts 15 years, the technology will be 25 years old by the time it reaches the end of its service life – and many satellites last much longer than expected. In addition, resupply is essential for International Space Station and commercial ventures are taking more of the workload and new schemes are being developed for servicing long-lived manned and unmanned spacecraft such as near-Earth satellites. Commercial Space ventures will continue to increase and reuse the ground facilities built and operated in support of orbital and space-transiting vehicles.

As discussed in Vono's paper, any such management model, to be useful, must be a) directly applicable to the sustainment of commercial space systems employed today; b) integrated, that is, internally consistent; c) practical, easy to apply; d) self-improving; and e) constant, unaffected by changing public laws, regulations, and management fads. It should be easily called to mind visually and via a short list of core principles. This is that model.

This paper is organized around only the 3 most important primary management subsystems (observation, risk identification, and fixing) and 3 supporting, but still critical, support areas (processes, technology, and people) required in sustainment management. Interspersed are 5 key principles.

II. Definitions

A good model description starts with definitions. Successful weapons system sustainment is defined as:

> "The continuous, effective support of the system to ensure continued mission capability".

"Mission" is the reason the system was built. When Google's loon system gets deployed, the mission will not be to play with balloons, but to deliver internet capability worldwide. Indeed, the mark of a successful enterprise is their ability to concisely state their mission and communicate it. For the USAF Strategic Air Command it was "Deter nuclear war". For loon, it is "Balloon-powered internet for everyone"[4]. A good mission statement leads to precisely-defined readiness factors that allow the enterprise to measure their ability to reach this goal, today and tomorrow.

In ICBMs, the system had to be available, reliable, accurate, and able to withstand nuclear attack. These were codified into precisely-defined readiness factors. Significant subsets of availability were "safety and surety". That is, the weapons would only be fused and triggered when allowed by the National Authority. A tourist space venture might have readiness factors of safety, reliability, and fun. A system poised to deliver internet to everybody will certainly have readiness factors associated with reliability and longevity.

In this model, the "system" must be completely identified and configuration-controlled for effective sustainment. What does "the system" include?

"System" is everything required for the mission. For instance, in the USAF, it is not just the aircraft, but also the entirety of maintenance, supply, engineering, test equipment, support equipment, and so on, required for the aircraft to function. If the aircraft has unique in-flight refueling requirements, for example, the system definition could even include the associated unique airborne tankers (as subsystems of the primary aircraft) such as the unique tankers, KC-135Qs, with unique radios, fuel tanks and other subsystems, needed for one receiver, the SR-71.

The ability to correctly define your complex system could be your first stumbling block. A good effort at this definition for your system could result in the realization that your sustainment organization does not, and perhaps never will, control important parts of your system. But the first step in problem-solving is clarity of the problem. So the question must be asked, do you even have a "sustainment organization"? It should be easily recognizable as the organization that controls the engineering baseline for your complex system. If the engineering baseline (another way to identify your system) does not exist or is incomplete, sustainment will be impossible.

"Self-improving" means your sustainment management system can repair itself like a wounded or diseased person and build itself up in specific bones and sinew like an athlete. It is helpful to imagine sustainers operating a "management machine" that changes as it is employed. That is, the organization can improve itself by incorporating lessons learned over time, correct its mistakes, and realize efficiencies. The processes for continuous improvement in the required areas are built into the day-to-day sustainment management subsystems. The sustainers making those management system work have a responsibility for it to change for the better. How this is accomplished is explained under risk identification.

"Complexity" is the next term needing definition. Whether the system is complex or simple is a judgment call. This paper deals with the complex system because the less complex the system, the more likely critical sustainment actions are taken as mere "common sense" and not analyzed nor properly designed and executed. For example, a simple system may reveal its deficiencies with little effort and present its risk mitigation solutions easily. On the other hand, the need to observe and analyze the performance of a complex system demands an understanding of how to design a thorough assessment program to systematically observe your system. In the same manner, once the sustainment management model is learned, the user can discard portions of it if the tasks in that area prove simple. For instance, well-understood wear mechanisms need not be thoroughly tracked if they become thoroughly predictable.

This sustainment management model is called "practical" because it provides an idealized and stripped-down management model that can be compared with the reader's real world experience. The model, even the fully-described model provided in the textbook, does not attempt to include every minor influence. This is done to keep it as simple as possible to ensure it is used, especially by the novice who too often find themselves surrounded by a morass of confusion and contradictions. The model, as a common paradigm, helps the team understand organizational requirements, justify process changes, and enforce discipline. Sometimes it keeps individuals from "losing heart" and quitting-in-place as it helps them realize that things are not forever "going wrong", but "identification and fixing" is how sustainment management actually works. That is, they are not hopelessly lost amid one crisis after another, but there are specific actions they can take to assume control.

The management model must be fully integrated, that is, internally consistent. This consistency can be achieved analytically by starting with the reason for the system, the mission. From this "watershed requirement", all the management subsystems and their internal processes flow. In other words, the mission is the prime requirement that drives all others, especially the sustainment management model.

Sustainment Principle #1: The mission is the watershed requirement for system sustainment.

III. Complex System Sustainment Management System (CSSMS) Meta Model

To best explain and craft your own processes within the Complex System Sustainment Management System (CSSMS), the CSSMS itself is defined and then the forces acting on it are analyzed.

See Figure 1. The CSSMS is composed entirely of "observe, identify, and fix". How these 3 functions work and how well they work in your sustainment organization is dependent greatly on how well your processes are crafted, executed, and improved. To do so successfully, the processes impacting them must be understood.

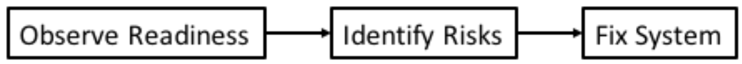

Figure 1: The CSSMS is "Observe - Identify – Fix".

Identifying risks to the mission soon enough for timely fixes only occurs if the system can be adequately observed.

See Figure 2. This is the weapon system sustainment meta model developed and used by ICBMs. 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.

The raw data needed to do this work comes from identifying risks to the weapon system mission with lead time to get them fixed. This is the "identify risk" function, also known as the Sustainment Risk Management System. Risk are written against the readiness factors mentioned above. So they are tied to the warfighter's mission.

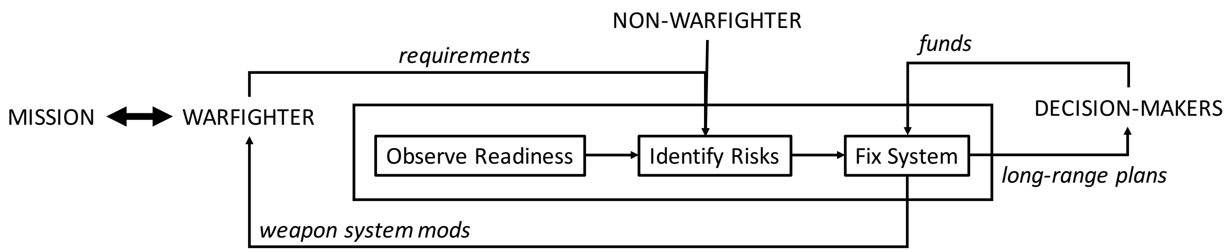

Figure 2: Weapon System Sustainment Management Meta Model

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. For remote sites, this can save a lot of money and other resources.

Warfighter requirements, such as missile accuracy, drive the readiness factors which directly impact how sustainment risks are written. There are also "fact of life" requirements like DoD standard desktop directives or environmental law which have no direct bearing on the mission, but must be responded to.

The sustainment organization has direct feedback to the warfighter, mostly in terms of delivering the weapon system and weapon system modifications they expect.

Now that the non-military world is building systems just as complex as ICBMs, how does all of this translate?

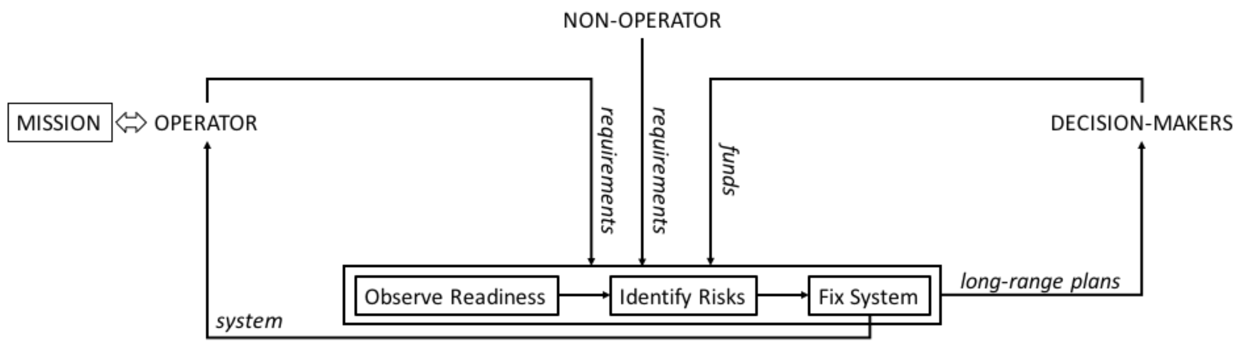

Figure 3: Complex System Sustainment Meta Model

See figure 3. The Weapon System Sustainment Mega Model becomes the Complex System Sustainment Mega Model. But not everything in the model is so easily or quickly translated.

In the "civilian world", as opposed to the world of military weapon systems, who "owns" the mission? When this model was developed for ICBMs it was easy to simply say "the warfighter" owned the mission and the sustainment organization was in a support role. Even in the military world, however, if the sustainer doesn't also feel ownership of the mission, they have less motivation to do their best. Good ICBM sustainment leaders, therefore, worked hard to make their organizations also felt ownership of the mission.

In civilian systems, consider a manufacturing company with a series of factories employing a large and sophisticated monitor and control system built around "Internet of Things" components. The best IoT design businesses will have designed the system using the best components for the job and avoiding locking the factory into a particular brand. (E.g., using smaller example, would you want to be "locked in" to an "Apple House" or an "Amazon House" if instead you could freely choose the best components and create the best design?)

In this IoT factory monitor and control system, who owns this mission? The factory leadership who decided they needed the system must have thought they had a mission for it before they contracted to spend the money. And whether the factory contracts with the installer for sustainment or provides sustainment in-house, the sustainer should adopt this mission as their own if they are to understand the system, the mission, and the readiness factors associated with the mission. Similarly, the operators and maintenance folks in a single, lone ground communications node of a massive satellite and ground network should know that their mission is to deliver reliable communications to all customers.

However, there are specific individuals who operate their portion of the system on a regular basis. And something almost magical occurs once a complex system has been designed, built, and deployed to the operators. They form a bond with the system in support of the mission they have been given.

This is most easily seen in pilots who, while at the controls, feel as though they ARE the aircraft. Truck drivers have a feel of their mass and bulk barreling down the interstate at 70 miles per hour. Perhaps the most common example is the feeling automobile drivers get. They may even blurt out "ouch!" if they bump a fender against a pole getting out of a parking space. This feeling is sometimes called "body schema" and the ability of humans to take on a tool, even a massively complex tool, as if it were part of them is often called "plasticity". Whatever tool or system you are using feels as though it has actually become a part of your body. The caveman would have felt the heft of his rock hammer in his hand and been able to skillfully use it as easily as tracing a drawing in the dirt with his finger. This body schema plasticity invades any operator brain, but also their psyche. It helps create within them a deep feeling of ownership.

Also, with complex systems and focused missions, the operator not only becomes one with the system, but is completely aware of how the system operates. That is, the operator cares little about the "design baseline", but does care very much about the "capabilities baseline" that they have direct, tactile, experience with. This focus on mission and system capability can drive requirements that operators feel will better support the mission by maintaining or enhancing the expected capabilities.

So, to conclude, it is the operator and the operating organization that "owns" the mission. But, just like in the military, the system sustainers must be indoctrinated to feel the mission as deeply as possible.

Back to Figure 3. This is the complex system sustainment meta model modeled after the WSSMS Meta Model. The activities in the "Fix System" box still include long-range planning, short term planning, deployment planning, requesting funding, and flowing funding to programs and projects.

The raw data needed to do this work still comes from identifying risks to the system mission with lead time to get them fixed. Risk are written against the readiness factors mentioned above. So they are tied to the operator's mission.

Risks cannot be identified unless the system is sufficient observed so that data and analysis can point to future degradations of the system.

Operator requirements, for instance, on-orbit stability, drive the readiness factors which directly impact how sustainment risks are written. There are also "fact of life" requirements like company software standards or environmental law which have no direct bearing on the mission, but must be responded to.

The sustainment organization has direct feedback to the operator, mostly in terms of delivering the weapon system and weapon system modifications they expect. And if the sustainment organization fails to understand and honor the operator's sense of capability, great unhappiness on all sides will ensue.

A. Non-operator Requirements

Any real world organization that is the realization of the CSSMS has many "bosses" who have the power to impose both good and bad requirements -- often with no associated direct funding to realize the solutions. The middle inputs of Fig 2 depict these "fact of life" realities. This is illustrated in the diagram by not showing any input arrow that might modulate these requirements. In practice, the organization may have some small influence on the decisions made about government regulations, international space law, or import restrictions, for example. But the influence is so minor that this model depicts the CSSMS as primarily reacting to outside influences over which it has little control. That is, processes must exist to not only recognize and respond, but anticipate and push back in those rare circumstances where this is absolutely mandatory to sustainment success. This part of the model can also include those policies that the company chooses to impose on itself for various non-mission reasons such as "good-neighbor" policies, eco-friendly actions, and others that might not be easily justified as essential to the core mission.

For example, to avoid contribution to the growing problem of orbital debris, satellites must now include considerations for end-of-service-life planning or disposal during the mission architecture design, manufacturing, and operational phases.[5] The U.S. Government Orbital Debris Mitigation Standard Practices (USGODMSP) require, at a minimum, either atmospheric reentry, maneuvering to a storage orbit, or direct retrieval. NASA Safety Standard 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris, codifies the Agency's plan for projects and programs to be consistent with the Standard Practices.

These standards also include rules for minimizing release of debris during normal operations, accidental explosions, and collisions. The Aerospace Corporation (Aerospace Corporation, 2015) assesses that the disposal rule is both the most critical for minimizing long-term debris hazards, while also being the most technically difficult and expensive to satisfy. But there can be good corporate reasons for establishing methods to retrieve near-Earth commercial satellites that were placed in orbit prior to these rules. One such reason could be to start a new mission to sell this service to others.

Thus, Non-Operator vs. Operator requirements may seem a distinction that makes no difference. A requirement might change categories depending on circumstance. And unfulfilled Non-operator requirements could spell the end of the system. But Operator Requirements, since they are closely coupled with the mission, hold a special priority: the reason for the very existence of the sustainment organization.

B. Operator Requirements

The ability of the system to perform its mission under control of the operator is the primary witness to how well the sustainment management system is working. The left hand side of Fig 2, is where the requirement for a system to support a mission is depicted. And the requirements flow and the deployment of the system, help drive the design of many important CSSMS processes.

Any system is designed and deployed with certain readiness factors or capabilities in mind. A near-space internet balloon designer may intend a 90% availability rate for launch, for instance. Once employed, the capability will naturally degrade unless steps are taken to constantly improve it. Simply maintaining the system will not be sufficient to avoid the "creeping entropy" that afflicts aging systems. The operator may discover the capability is not as advertised or simply not sufficient. Then there is the example where the capability far exceeds the design requirements (the designer's baseline). At this point, the operator will see this capability as the new standard and will be insistent they continue to get nothing less.

Sometimes the requirement arises because of a modification the sustainer has made to the system and then delivered to the using company and their operators. Not depicted, but it has even been known to occur that the operator has made an unauthorized change to the system that the sustainment organization must now find a way to sustain. Other times, there is a mutually-agreed to evolutionary action that takes place to support or improve capability.

The first-generation polymer 3D printer on the International Space Station was built by Made in Space, Inc. for NASA as a technology demonstration. To streamline the development process, the 3DPrint demo was designed and built to operate inside the ISS Microgravity Science Glovebox. This allowed the hardware to avoid building in another layer of containment, but also meant that any operations needed to be scheduled around the availability of both the Glovebox and astronaut crew time for installation and de-installation. Removal of this limitation was a high priority for the operators, the astronauts.

The current-generation system on the ISS is the "Additive Manufacturing Facility" (also built by Made in Space and operated as a commercial enabling capability). The AMF was designed and built to operate as a standalone payload inside an International Standard Payload Rack. Its only consumables are available power from the ISS and feedstock from exchangeable cartridges. Once installed, the only touch labor by astronauts is part removal and cartridge exchange. The hardware is entirely self-contained and includes an environmental control system that ensures no harmful byproducts are released into the cabin air. The system is also designed for remote operation from the ground, but also includes a touchscreen for astronauts to do custom operations.

Note that Figure 2 does not show a direct linkage between warfighter requirements and the stream of funding. A naïve sustainment team member might think that requirements come with the funding to realize them. In fact, that linkage *is* the CSSMS. That naïve sustainment team member *is* the link, as is explained in the next sub-section, "Funding".

C. Funding

The right hand side of Fig 2, the funding cycle, drives the creation and use of the primary management subsystems described next. The link between the warfighter requirements and funding is the CSSMS.

Sustainment Principle #2: In achieving sustainment goals, it is a daily fight to justify funding needs.

Funding flows to the CSSMS from multiple sources along with multiple time-factors and rules of use. These funding sources require specific information from the CSSMS to enable them to allocate and distribute funds. The information that funding organizations need from the sustainment organization, in summary, is a rank order and time-phased list of programs and projects needed to mitigate or eliminate risks to the mission. The list must be integrated with accurate information about the risk being mitigated in terms of effects on the mission.

The plural, "funding agencies" depicted in Fig 2, refers to the reality that many internal and external agencies control funding that the sustainment organization needs for success. In the military, various streams of funding with their own unique rules arise primarily due the needs for various military organizations to report spending to the US Congress. A large commercial enterprise that provides renewable energy systems may find, in addition to profit on sales, a significant part of its funds from governments willing to encourage this industry. This creates the requirement to satisfy that agency with the required information, as one example.

This funding complexity could mean that the beginner will likely feel a bit overwhelmed with the process. But the beginner will become an expert over time, and this complexity serves the expert well. A roadblock in one funding stream might be overcome with some creative re-programming from another funding stream. The expert will find it important to keep their eyes open to new potential funding streams that will appear from organizations with vested interests in promoting certain types of solutions. In commercial systems, this include various forms of marketing.

The interface between the sustainment management organization and the funding agency is worked by individuals on both sides who have the same need for quick, accurate communication concerning up-to-date system knowledge and prioritized risk mitigation solutions, that is, programs. Both types of individuals need a strong grasp of the rules and how the weapon system functions to meet the warfighter's needs. For instance, a sustainment organization may have a program manager desperate for funds to complete a high priority flight line test equipment modification that boosts their system's availability. The funding manager on the other side of the interface, perhaps a sales and marketing person willing to provide money for advertising, must be able to cogently and concisely convey this to their management based on an accurate understanding of the complex system. The sales and advertising organization may not be deeply committed to your system's mission, but they want to back a winner. So they must know something about your system and your mission. They must also help their bosses prioritize this system against other systems they are considering.

Beginner or expert, in the organization or just outside it, all need the information generated within the sustainment management organization. And they need it formatted in a way that makes it easy to justify their needs to the agencies and easy to get creative with funding streams. The majority of the remainder of this paper will focus on how the various processes within the CSSMS can be derived from this need.

IV. Primary Management Subsystems

Within the CSSMS, the three management subsystems are observe, identify, and fix (O-I-F). These subsystems and their associated processes are created and executed in response to the need to continually create a rank-ordered and time-phased list of programs without continuous reliance on the operators. If an operator expects 90% availability, the sustainment organization can observe the system in an attempt to predict if the availability will decline anytime soon. If it appears this might happen, identification of the risk is next. And then plans can be made for a fix before the operator even becomes aware of any degradation in availability.

Refer to the right side of Fig 2. Funding will not flow without having and being able to communicate the rank-ordered and time-phased list of programs. Without this funding, your CSSMS organization would not long remain in existence. With the wrong funds at the wrong time, the system becomes more expensive, or perhaps impossible, to employ.

The information referred to in shorthand as Long Range Planning on Fig 2 is primarily produced and formatted by acting on the information flowing from the Sustainment Risk Management System. That is, risks to the mission get identified. The identification step, the I in O-I-F, in turn, requires the information flowing from the System Assessment Program, the observe part of O-I-F. All of this helps create the long and short range plans which are primarily a description of the many programs and projects required to mitigate the identified risks. Although some activity might be relatively immediate, the fix part of O-I-F is termed "Long Range Planning".

The observe part of O-I-F, assessment, is often called a program and not a management process because only an on-going program can consistently support the system with the information required for risk and planning. Observation is an ongoing activity that continually assesses the state of the system. Observations are used to determine risks to mission capability. These risks are prioritized and fed into long range plans to determine what efforts need to be performed to maintain or enhance mission capability.

Explanation of these sub processes begins in the center, with identification via the sustainment risk processes.

A. Identify Sustainment Risks

The position of risk at the heart of Figures 1, 2, and 3 is revealing. If the sustainment risk program cannot take assessment data and efficiently transform it to risk mitigation plans the entire system sustainment process breaks down. This results in a "sustainment via crisis" management model. This is just one reason that imposing the disciplines discussed in this paper starts here. "Identification" can push the sustainment organization to do a better job at both observing and fixing.

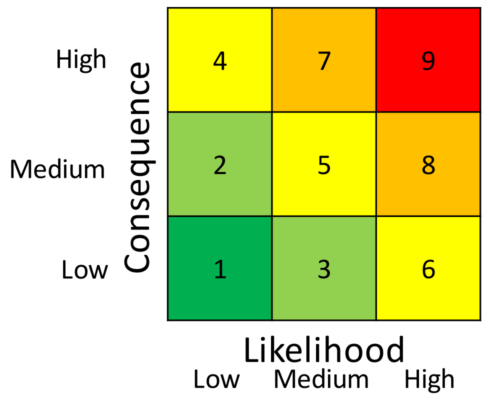

Figure 4: Risk Matrix. *Most managers are familiar with a risk management system. Consequence and Likelihood define the priority of the risk via a matrix.*

The generic concept of "risk management" is extremely popular and there are many ideas floating around about how to run a good risk management program. There are many vendors willing to sell your organization a risk management program. This is usually an information management system (IMS) of some kind. Because of all this, your organization likely already has rules and processes on risk management. But they may not be following good sustainment risk management principles.

Sustainment Principle #3: Sustainment risk management is the primary driver of efficient sustainment management.

The Risk Management process and its supporting rules and software applications must be, first, a "sustainment" risk management system. Good and useful risk system exists for a variety of reasons. But if an item identified in the risk system is focused on mitigating a schedule risk to a development program, or helps ensure a desired profit for the year, it is not a risk that should be listed in a *sustainment* risk management system. The key to ensuring a management system that is operating on risks to the sustainment of the weapon system is to expend the effort first to identify the operator's mission and second to identify a handful of key readiness factors critical to the mission.

For instance, a manned bomber (the weapon system) supports a warfighter's mission to destroy any target worldwide within a specified time period. The sustainment professional creating or improving their sustainment risk system must research this mission and understand it. Similarly, an established transportation shuttle to and from an asteroid mining field supports the operator's mission to provide reliable transportation of equipment and ore at low cost. The sustainment professional creating or improving their sustainment risk system must thoroughly understand the precise definitions of reliability and economy and be able to recognize threats to these readiness factors in time to do something about them.

So, the professional needs to propose a handful of readiness measures that can be tracked to ensure the mission can be adequately performed. Usually "availability" is the first one. If a sufficient number of systems are not mission capable and cannot be generated in the specified time, the mission fails before it begins. Or the commercial enterprise is doomed as customers and potential customers are disappointed.

Another typical parameter is survivability. The weapon system must reach the point where, in the case of a military bomber, bombs are dropped. They must survive all the way to the target. (There is likely a requirement for the bomber to return home as well.) Can your asteroid shuttle survive long periods of time in the harsh environment of Space? What critical components will fail first and how will this affect your mission? What do you do to keep the vehicle working?

Depending on the mission and the weapon system, there will be other parameters such as accuracy, loitering, recon spectrum, etc. Finally, as a special subset to availability, there will be existential parameters such as safety or surety. If a weapon system is deemed unsafe to use, it cannot be used until the issue is fixed. All of these have analogues with the Commercial Space mission. And others will be uncovered as companies hold risk management meetings and questions of mission and readiness are discussed.

All this introspection is needed because when a risk is proposed, it must be tagged to one of the key readiness parameters. If this cannot happen, the risk must be discarded as not a sustainment risk, *or the key parameters must be updated to include the broad requirement behind the current issue*. The phrase in italics is an example of the self-improvement built into this sustainment management model. In this manner, the risk system is kept focused on sustainment and the readiness parameters are updated with up-to-the minute understanding of the system's role in the mission. Both of these functions, updating the risk list and keeping the risk process healthy, are the two key tasks to be performed in each and every risk review meeting.

Low	Medium	High	
+2	+3	+3	Cannot be mitigated before impact
+1	+2	+2	Can just be mitigated with ample lead time for fix before impact
+0	+0	+1	Won't be a problem anytime soon

Figure 5: Time Value of Risk.
A significant improvement to ICBM risk management occurred when a time factor for risks was inserted into the process.

See Figure 5 for an example of a significant process improvement that came about due to focus on readiness parameters and the mission. It became clear after hundreds of risks were prioritized that he time-factor was not being sufficiently discussed at risk meetings. So a factor was added to take this into account starting with the very first presentation of each risk.

To elaborate, items listed in the risk system will have a rank-order in a priority list based upon their impact to sustaining the weapon system, and the likelihood the impact will occur. A third factor relates to the time-value of the risk. Just as a dollar today is not equal to a dollar in ten years or ten years ago, a risk has a time-value. Risks may be anticipated to come to realization in the near term, mid-term, or long term. These 3 time periods vary with the risk and are associated with the lead time to implement the mitigation. Rules governing these rules must be precisely defined, widely communicated, and changed as needed. These process-change issues are part of the Level 1 Sustainment Risk Review meeting. More about this under the section "Instill Discipline via Practical Processes".

Who attends a sustainment risk meeting and when do they occur?

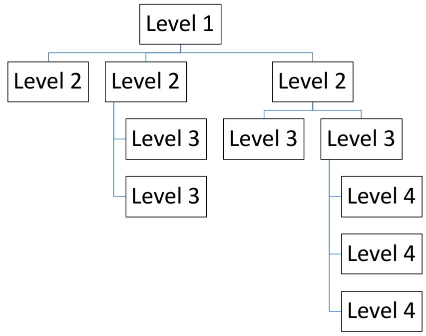

Figure 6: Organizational Structure by IPTs and Levels

Refer to Figure 6 (and read the section on "Instill Morale by Ensuring People Have a Purpose" below) to understand the term "Level n". Today's effective organizations consist of many integrated product teams (IPTs) each staffed with the various and sundry expertise required for their piece of the sustainment task. For effective risk management, monthly meetings chaired by the "Level 1" leadership are a must. Various levels underneath the boss can be tagged as "Level 2", "Level 3", and so on as needed and also give the name of their area of responsibility. Each of these tiered management levels may be charged with having their own monthly risk reviews to identify and refine risks to be presented. For this to work properly, as a minimum, each level 2 organization must have an individual commissioned to develop the expertise to use the risk system and be able to dialog with the key experts to draw out emerging risks. This is the risk integrator. This can be an additional duty. The level 1 risk meeting should be open to anyone desiring to be there. However, most of the indoctrination for most sustainment team members will occur at level 2 or level 3 meetings that are facilitated by the level 2 risk integrator and run by the level 2 or level 3 manager respectively.

Risk integrators can work with each other and the boss's risk system administrators to track metrics, help improve the meetings and processes, and train new risk integrators. As an example of metrics, the International Space Station Integrated Risk Management Application tracks such strategic measures as "staleness" - the timeliness of risk data, "mitigation tardiness" – the timeliness of mitigation plans, "time in system" – the length of time required to close a risk, and the "Risk Organization Breakdown" – the type and quantity of all open risks in the system. Individual items are assessed for consequences on cost (low risk), schedule (medium risk), and technical (high risk) concerns.[6] (Perera, 2005)

Rules intended to spread cooperation and knowledge are enforced. Every person is responsible to identify a risk on any concern they find. Support is provided to write the risk and defend it. Not every risk survives scrutiny from Level 3, 2, and 1 IPTs. But every risk is vetted.

Enforcement of rules in the workplace depends greatly on their acceptance by the people in the organization. Here are a few common-sense rules that can be introduced with some confidence they will be accepted. They can be adapted to better fit your organization.

- Every member of the organization has a right to create a risk based on their personal judgement. Their IPT risk integrator is required to help the individual write the best version of the risk they can for presentation to their IPT's risk board.
- Every IPT will hold a risk board no less than 6 and no more than 14 times per year. This does not include the annual complete review of all risks.
- Disagreements on system sustainment risks are encouraged and will be judged by the Level Manager. If either party is unhappy with the outcome, it will be presented and judged by the next higher level manager. This will repeat as necessary since only the Level 1 manager can accept the responsibility for an unmitigated risk.

Leadership may decide that it is more efficient to discuss all risks (sustainment, programmatic, profit, etc.) in a single recurring meeting. The danger of doing this is that it confuses the team and causes them to lose focus on sustainment. The risk meeting does far more than identify sustainment risks and their mitigations. It indoctrinates the entire team on what defines a sustainment risk, helps them memorize warfighter readiness concerns, and weapon system capabilities.

Risks must be identified as soon as they are well enough understood to be defined. The process cannot wait for a suitable mitigation to be thought up. Good risk integrators help ensure this occurs. The corollary to this is, the risk management chair must never castigate a speaker for not having a remedy for a risk which is brand new.

You know you have a good sustainment risk management program when a) process discussions occur during risk management meetings illuminating understanding of readiness metrics, and b) some routine risks can be successfully processed via emails with risk integrators and managers.

Risks are usually found because of new information from the Assessment program or a fresh look at existing information.

B. Observe The System

Sustainment requires an affordable, systematic assessment program to sufficiently observe the system and compare it to not only the designed-to requirements, but also the capabilities expected by the operator -- also called the capabilities baseline. This must be done with sufficient coverage to detect degradations and with enough time to mitigate the degradations successfully.

Sustainment Principle #4: Without an effective assessment program, sustainment is flying blind.

There is no hope of ensuring a system remains capable of carrying out its mission if it is not sufficiently observed. With complex systems, operators cannot detect hidden degradations that someday will cripple their system. So “Sufficiency” is achieved by processes that not only observe and assess the observations against expected capabilities, but also assesses the assessment process to ensure there are no gaps in coverage. Example: the sustainment organization has expended $10M each year to carefully track cracks in all returned first stages to ensure structural integrity for reuse. Meanwhile, evidence of potential new failure mechanisms associated with unexpected bending modes found during refurbishment are lost when technicians and engineers do not retain and review the data.

The Assessment Program can never be completely sufficient, or in other words, perfectly thorough. But a credible effort can be made to minimize surprise breaches of failure limits and operator expectations. The program must be designed as multi-year, with a built-in opportunity to review it each year for improvements. The program is guided by the handful of readiness factors mentioned above such as availability and reliability. The responsibility for the system is parceled out and allocated across the organization at each management level. At each level a comparison is made between assessment observation and testing, readiness, and system components. Testing and observations are made ideally as a whole system during operation. There are limits to full observation at this level and often issues detected at this level are detected too late to respond before significant degradation is a reality. So observation and testing must occur at subsystem, component, and part level as well.

If the sustainment organization does not have a deep understanding of the system “as-employed” capabilities, (the capabilities baseline) the operator definitely does. And any loss to that baseline will be seen by the operator as a failure of the sustainment organization. At the same time, the sustainer must thoroughly understand the designed-to and as-built capabilities so that they have the clearest picture possible of system effectiveness. Example: a fleet of rockets is experiencing aging of its solid fuel. The warfighter expects 100% reliability of the fuel. The mission specifies that the rockets be designed to 90%. The as-built rockets were tested to 95%. The sustainer detects degraded fuel and creates a program to re-load existing rockets with new fuel, but over the course of the program, reliability will drop to 88% for 3 months and be below 95% for 8 months. Can this be sold to decision-makers? If 88% for any length of time is completely unacceptable to operators, the primary fault lies with the observational power of the assessment program.

The sustainer should enshrine this operator-expected capability as the new capabilities baseline because the operator will no longer settle for the designer’s baseline. However, the operator and the sustainer can come to an agreement that a certain excess capability can be considered “margin” against future degradation. That is, some capability may be lost as fixes are designed and sent to the field. The operator may be willing to accommodate a temporary breach of expected capabilities if the benefits are real and no other solution is possible. The sustainer may wish to have some "management" margin as insurance against late detection of issues.

If the sustainment program is not systematic, the sustainer will not be able to prove to top leaders that the system will achieve its desired life. A systematic program has documented proof that it has followed sound scientific approaches for testing and monitoring. Testing and monitoring results are also well-documented. With complex systems this will involve one or several IMS to hold the data in a retrievable fashion. Example: top leaders expect a communications satellite to meet needed capabilities until it is replaced in 7 years by the next generation. However, all the test data indicating stable reliability and weapon system configuration is stored on paper in file cabinets and the engineers are unsure if the tests that created the data are the same from year to year or exactly what the configuration of the deployed force is. Decision-makers are, therefore, not confident in this weapon system or its estimated life.

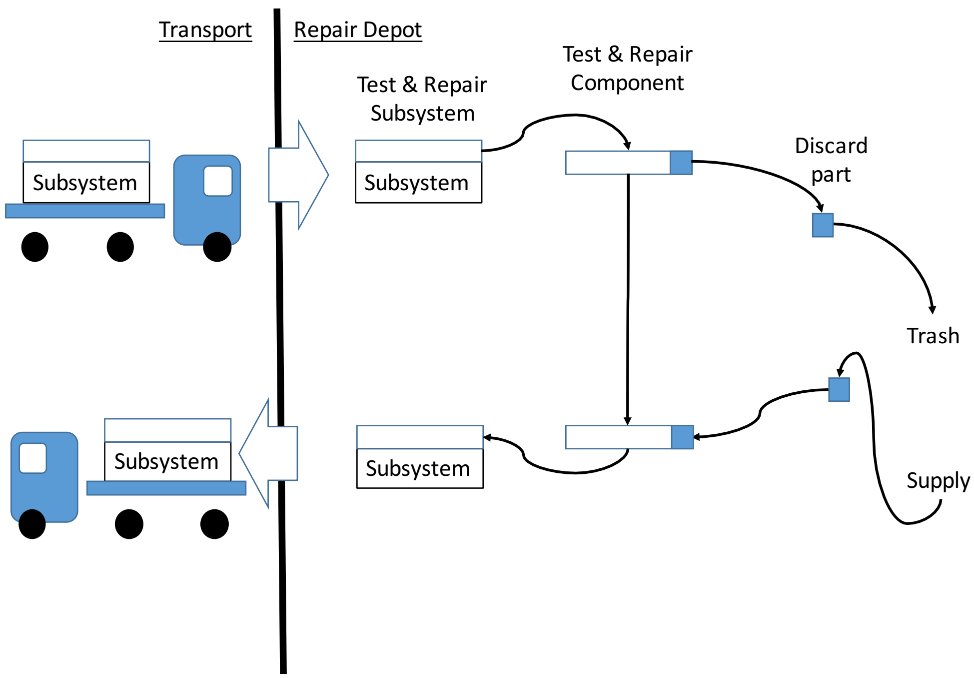

Figure 7: Affordable Repair.
Test only as needed to identify suspect subsystem, components, parts, then remove and replace.

Care must be taken to ensure the same data are not retained in more than one information management system since this will increase data maintenance costs and data will drift apart if neglected. Example: A depot keeps track of the serialized subassemblies as they transit periodic inspections and routine upgrades. But no effort is made to double-check accuracy. As the assessment program compares epoxy upgrades, the same serial number component appears to be in multiple locations at the same time, reducing decision-maker's confidence in the upgrade.

An affordable assessment program starts with a survey of all "free" data which is generated during the normal use of the system. The term "free" is used very loosely here as there will be some costs to the Assessment Program. Operational data are captured by flight line maintenance logs, post-flight maintenance briefings with crews, mission documentation, and similar sources. The ICBM program found that a rich source of degradation and overall system health is the repair depot. Often, especially in military depots, the focus is on throughput and production to drive down repair costs. See Figure 7. The sustainment organization, if it does not control the repair depot, must enter into a relationship with the depot to supply funding in exchange for information. Despite being removed from military standards, a good model to use as this is initially established is the FRACAS programs used in weapon system production (MIL-STD-2155). See Figure 8. Material Review Boards are replaced with Failure Review Boards. Additional diagnostics will be run beyond the needs for simple diagnostics and repair. Depot information management systems will interface with deployed systems information management systems to tease out information like components that fail, get re-installed in another vehicle, and fail again with the same symptoms.

The standard should be set that all failures will be understood and repairs will be consistent with the symptoms spotted in the deployed asset. Failures of components during repair will get the same scrutiny. This does not mean, however, that every failure and repair will result in full post mortem analysis down to the dissected part. The majority of failures will be repeats and can be categorized with minimal effort. The Assessment Program has a continuous role keeping the repair depot aware of what data are of great importance and what data are not worth collecting. Example: Space communications ground stations send their power supplies to a repair depot for refurbishment and reuse. When they transit the repair depot for inspection, disassembly, repair, refurbishment, and reassembly, additional diagnostics or parts analysis are not called for if inspection indications are typical of well-understood failure modes.

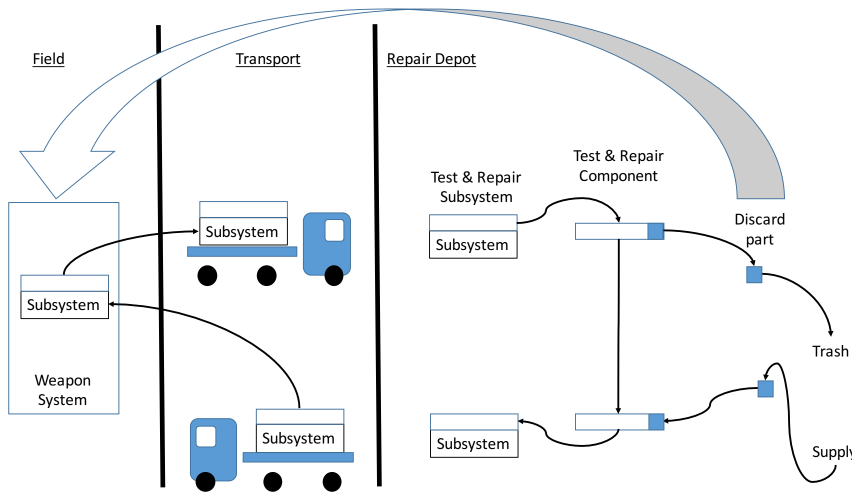

Figure 8: Affordable Repair with Observation.
Test sufficient to discover emerging failure modes.
And ensure repair occurred to the failure mechanism that could have caused the failure.

There will be gaps between what this "free" data can reveal and the requirement for full observation. Those gaps can be filled with age surveillance, revised repair depot processes, and special tests. These tests are expensive and must be well-planned to ensure scarce funds are used wisely.

Age surveillance is an assessment program that first establishes via analysis which components may age out or wear out. Periodic observation or testing is established to track the parameters that will reveal the rate of this wear. Key affordability characteristics include the use of alert limits to help establish wear rates, and then, if wear is detected, actual failure limits are discerned. This is because establishing actual failure limits for all components is too expensive and unnecessary unless trends are detected.

Special tests will be needed from time to time to fill in the gaps in knowledge that the various processes above do not cover. Special tests are performed at the most logical site. They may be associated with lack of knowledge of a failure mechanism, a surprise degradation, or age surveillance that only needs to be executed rarely such as electronics degradation.

Assessment is, at its core, a pursuit requiring attention to the scientific method and proper use of statistics. Like any scientific pursuit, numbers and what they measure are at the heart of the method. The handful of readiness attributes (such as availability and reliability) must have numbers associated with them such as "the warfighter must have 90% of their weapon systems ready for combat within 1 hour". With this precise metric, the assessment team can fashion inspections, monitoring, and testing to estimate whether that criteria will be met.

It cannot be proven in any scientific or mathematical way that any particular set of statistics can predict the future. However, the sustainment team has to be willing to assume the philosophy that trends can be mathematically estimated, the physics behind the trends can be understood, and the best approach is to expect the trend to continue into the future unless altered by another emerging degradation mode or risk mitigation action.

All of this means that the sustainment team must have members knowledgeable about the science and engineering inherent in the weapon system, members who are statisticians, and managers with a good working knowledge of both. For example, (and this is true story) a statistician spent two weeks thoroughly analyzing battery test data and proudly showed the battery engineer his prediction. The engineer applauded the mathematician's efforts but sadly informed him that "this kind of battery just doesn't behave that way when it gets old and worn out". Engineers (not necessarily degreed, but possessing engineering knowledge of the weapon system) and statisticians must be paired in their analyses. And managers must understand enough technology to explain the issue and enough statistics to explain why the technique used was appropriate.

The handful of readiness factors such as availability and reliability, must be constantly honed to be precisely accurate descriptions. At the same time, they must be measurable. The associated breakout of metrics the sustainment team estimates must be simple to understand and drive appropriate organizational behaviors. Every member of the assessment team must know them and compare them to their daily actions. Both assessment and risk, being revelatory in nature give the opportunity to better understand and precisely define the warfighters' core needs. On the measurement side, attempts at calculating the precision of estimates of actual performance against these factors are frustrating, but will serve to caution managers against believing the estimates themselves are precise.

Sustainment Principle #5: Readiness must be concisely, precisely, numerically defined and scientifically pursued.

Frequently, the assessment program will come up short and this in itself creates a risk to sustainment. When this happens, a risk must be written and presented to the sustainment risk management board.

You know you have a good Assessment Program when degradations to readiness are detected soon enough that mitigation actions or programs can keep the weapon system operating at the capabilities baseline.

C. Fix The System

Sustainers are faced with an existential problem every day. Can they continue to justify the very existence of their system and, by extension, their sustainment organization? Can they convince top decision-makers that the system can economically be sustained for many more years? Are the list of risk mitigations and associated programs worth the funds requested? Do the top leaders have confidence and believe that performing these programs will keep the system supporting the warfighters' mission? The sustainer has a responsibility to provide these executive decision-makers with cogent, prioritized explanations of the system needs.

The output of the risk management program provides the fodder for this action, a prioritized list of risks and their mitigations. These mitigations will range from simple changes to procedures to large programs to acquire new support equipment or even major system modifications. Before these actions can be justified, funded, and started, the sustainers must create an overall long range plan that shows how the numerous fixes can be time-phased and resourced. Often, the sustainer must contend with a myriad of funding sources each with their own rules.

In the case of DoD weapon systems, there are multiple top decision-makers across many government organizations with the power of allocating funding. Within these organizations, funding is tracked per congressional edict, DoD requirements, and service (such as USAF) regulations, through various accounting channels. Funds will have time limits as well. These Congressional Edicts, DoD and service organizations, and other rules have a tendency to change frequently. Thus the sustainer must have experts on staff who can look at current and future fixes, current rules, and program an overall plan that not only allows for the sustainers desire of fixes lead time away from degradation but also works with the funding available.

Non-government complex systems may have complicated funding paths as well. Examples can include not only internal company funding paths, but taxation considerations, project partners from other companies or the government, international cooperation, and so on.

In the case of some sprawling and remote complex system, there is a deployment plan that needs to be created as well. For instance, in poor planning, subsystems that have just completed programmed maintenance immediately return to get a modification that could have been included in the programmed maintenance. Support equipment is pulled from the field for modification just as it is needed for a surge. Procedure updates become confusing because they were not synched with on-going modifications. In all of this, configuration identification and control is a must.

V. Support Areas

Sustainment organizations cannot consistently evolve to meet emerging needs without agile processes, effective IMS, and dedicated people.

A. Instill Discipline via Practical Processes

The need exists for the CSSMS to respond quickly and affordably to both operator and fact-of-life requirements changes. Great organizations are able to do this by constantly improving their efficiency despite changing out of personnel, new laws and regulations, and other impacts on how business is accomplished. Failing to respond because your processes have not kept up is unacceptable. This leads to the requirement for the CSSMS to have consistent processes that get updated in a timely manner. This is accomplished by placing emphasis on a) the processes used to update processes and b) the audit process.

Audit processes must be consistently about reviewing the process and not reviewing the person. The auditor must cultivate a cooperative atmosphere that draws out the needed changes from the process owners and implementers. Once these are identified, there must be a responsible person to grab the process changes and get them through review and sign-off. Top managers are key to this process as they cannot simply reject processes, but may at times even need to get "down and dirty" with the team to ensure process changes never linger due to management approvals. Metrics on audit coverage and process update times are critical to the managers and leaders to ensure they take the time each week to focus on whether the organizational processes are healthy and improving. Without active leadership on a weekly basis, the organization and its processes will stagnate. Sustainment affordability and effectiveness will immediately suffer without immediately understanding the real cause.

A great process system allows for changes to processes to occur within one week and never take longer than two weeks.

B. Exploit Technology using Common Sense

The affordable use of technology, especially information management system, is critical to the affordable functioning of an organization charged with sustaining a complex weapon system. Complexity leads to massive amounts of data associated with massively complex subsystems, components, and parts. Tracking the associated data so that the system can be evaluated is a complex task on its own. Creation of and updating of information management systems is critical to managing this vast amount of data. This massive amount of data means that you must have information management systems to reduce the data in a way that is both manageable and meaningful.

Information management systems are often mis-designed, are duplicated leading to divergent results, and are often hard to correct. It is well worth the manager's time to ensure these problems are recognized and solved.

The first step in managing the organization's IT tools is to understand that the organization heavily depends on these tools for their day-to-day work. Encouraging the evolution of the organization and its processes results in tremendous frustration unless the tools can evolve along with them. New information management system must be developed in small, rapid cycles which takes into account the parallel evolution of the organization and its processes along with the new tools. Old tools must be able to be rapidly updated to ensure they keep pace. This requires active management which respects the users' needs while balancing the need to not make too many changes at once. Adequate budgets, actively seeking user inputs, and a track record of responding to organizational needs are the signs of healthy IT support. Lengthy contractual actions to create data bases, systems optimized to system administrator needs (not sustainers), poor and difficult access to data, and contradictory data are signs that this part of the CSSMS needs attention.

Put a different way, we are beyond the point where resource-holders deny any funds for software maintenance. Most intend that the use of automated information management systems will change the way our organizations perform for the better. Yet we still too often establish long lists of requirements that take far too long to implement, leaving the organization to evolve as the information management system stays static. The organization does evolve as it faces new problems and challenges. These normal changes in organizational structure, responsibility, and processes should not create continued frustration with lagging information management systems.

Thus, managers must allocate resources with a priority towards quick implementation, real expertise, and affordable solutions. Never let "better" be the enemy of "good" if it slows implementation. Give user's groups the

power to allocate the scarce IMS creation and improvement resources with a light touch of management oversight.

C. Instill Morale by Ensuring People Have a Purpose

This chapter discusses the most intensely complex part of any complex system, people. Below are a few key approaches to take immediately to direct that complexity towards achieving the mission. Central to all this is making sure each person knows their purpose, and knows they are expected to take the lead to achieve that purpose.

<u>Everyone benefits when everyone is a leader.</u> You, yes you, are a leader. It does not matter how you see yourself in your mind or on the organizational chart. Practice leadership techniques and you, and those around you, will be better off.

<u>Leaders remind people their purpose is worthy, useful, and valued</u>. One of the most loving things that great leaders do is they sincerely remind people, one at a time or in groups, that they, and you, are pursuing something important, perhaps even critical. At the core of every human being is a desire to be needed and valued. This is especially amplified at work where even the less astute realize that unneeded people could be "let go".

<u>Coach as needed, but keep corrections private and focused on behavior</u>. Praise in public. Criticize in private. It just works better for everyone that way. Sincere praise should be plentiful, but it takes practice. Criticism of another, done well and away from audiences, often results in you finding out things about yourself – things that you, personally, could have done better. Good coaches know that they can improve as well.

<u>Don't pretend you can accurately peer into the other person's inner world</u>. The Bible's command of "Judge not!" combined with other commands to "correct your brother" means that people have always had a hard time separating a person's actions from their motivations. It is better to say: "Marcia, we can't charge toys to our business travel credit cards. It really has to stop. Can we agree that you will do that?" If you start with: "Marcia, I know you love your kids and you feel bad you can't provide them all they need and you want to use your company credit card in places you know you shouldn't…" you will soon find yourself in a hopeless quagmire.

<u>Notice those losing heart and encourage them</u>. It may seem that nothing is sadder than a person who has quit in place. But that person can be "patient zero" who starts to rot the organization's morale and make everyone feel hopeless. THAT is much sadder. Help them before they are excised and discarded like surgery to remove an infection. Lend an ear. Try to help. But don't get infected yourself.

<u>If you have the power, organize people to achieve their purpose, not yours</u>. There are good organizations that make the work flow easier and there are bad ones that seem designed to stop all progress. The perfect organization for sustainment is described in this chapter under the "organizing people" section. These organizational constructs come with helpful rules to be applied in sustainment organizations. Refer again to Figure 6.

In Minuteman III sustainment, several IPTs are focused around subsystems, for instance, propulsion, guidance, ground. And there are lower level IPTs within these subsystems to be responsible for the components of these subsystems. The focus in each IPT is how the readiness factors are faring within their area of expertise. Top management form the level 1 IPT. Major subsystems and functions form level 2 IPTs, and so on. This could be called "nested integrated product teams". A similar organizational structure could be what you need for your complex system.

<u>Don't descend into stereotypes, get to know the person</u>. There are more prejudices deeply buried in your psyche than the obvious racial, religious, or political ones. In a Department of Defense multi-faceted team, for instance, it is easy to think every contractor is looking only for company profit, every civil servant is there to homestead inside a

comfortable bureaucracy, and every uniformed military member focuses their thinking on how to attain their next rank. Your team will have similar prejudices. Don't fall for them. Everyone is an individual.

VI. Conclusion

The trend in this new century is towards complex systems that remain viable for decades. Therefore, sustainment is not only becoming critical, but must also be carried out as economically as possible. If leaders do not make effective and economical sustainment processes a priority, their teams will be thrown from one crisis to another. This paper provides sustainers, leaders and their teams a simple model to compare with the reality of their day-to-day activities. The hope is that they will recognize when and why their approach is not providing the best system to their customers and operators, and take appropriate action. These actions are not always easy or simple, but knowing the correct path forward is half the battle.

You will know this or similar model is being applied in your organization when:

- Risk management meetings are held monthly.
- Risk Meetings include discussions of how the risk impacts the mission.
- Any meeting can be paused to discuss the governing process with an eye to improvement.
- Assessment results lead not only to risk identification, but also assessment program improvements.
- The assessment parameters are clearly defined and measureable.
- Long range plans are updated continuously.
- Information management systems routinely get updated at the request of the using team.
- Managers and leaders allocate resources, time, and priority for process improvements.
- Everyone in the sustainment organization can recite the mission, needs, and readiness factors.

Acknowledgments

The author wishes to acknowledge unique confluence of circumstances leading to the evolution of this weapon system sustainment management model into its current form. Sometimes the USAF didn't quite know what to do with strategic missiles in an airplane organization. But they knew enough to keep the experts together as a team: the many uniformed military, civil servants, and contractors who, over decades, developed this model through brainpower, luck, and sweat. These are the unique men and women who have spent their lives since the 1950's keeping our nation's Intercontinental Ballistic Missile (ICBM) weapon systems on alert and deterring attacks against our nation. Operators have retired and joined sustainers as contractors. Military members have successfully employed their University of Southern California Master's Degrees in Systems Management (a unique program for mid-level officers to learn weapon system management). Dedicated civil servants dutifully applied principles with discipline and added their own creativity as the uniformed military and contracts came and went. And the nation very much owes a debt to the systems engineers of TRW, Inc who first helped the USAF create ICBMs and stayed up through the millennium sustaining them to ensure their continued success.

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