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WHY THE SURVIVABILITY ONION SHOULD INCLUDE RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM)

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September 2013

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Reliability, Availability, and Maintainability (RAM) and Survivability are both diverse disciplines that explore how a system will perform when placed within an operational environment. This Joint Applied Project provides a qualitative analysis of the interconnectivity of RAM and Survivability. It shows that an in-depth RAM analysis ensures military personnel are better protected throughout the life cycle. Methodologies for improving reliability and maintainability are also presented, to include physics of failure, highly accelerated life testing/highly accelerated stress screening, preventative maintenance determination and pit stop engineering. This analysis uses an Active Protection System (APS) to show that, when RAM is included in the Survivability Onion; both Survivability and RAM evaluations benefit; survivability assessments become more complete; RAM assessments are completed sooner; and ultimately, better systems are put into the hands of service members. As APS requirements are developed, it is important that they include the Materiel Availability Key Performance Parameter with associated Reliability and Ownership Cost Key System Attributes. When evaluating an APS (or any system) the independent evaluator team members need to integrate and discuss the impacts of the capabilities and limitations they observed with each other to ensure that the deficiencies are properly addressed in the reports.

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Submitted in partial fulfillment of the requirements for the degree of

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WHY THE SURVIVABILITY ONION SHOULD INCLUDE RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM)

ABSTRACT

Reliability, Availability, and Maintainability (RAM) and Survivability are both diverse disciplines that explore how a system will perform when placed within an operational environment. This Joint Applied Project provides a qualitative analysis of the interconnectivity of RAM and Survivability. It shows that an in-depth RAM analysis ensures military personnel are better protected throughout the life cycle. Methodologies for improving reliability and maintainability are also presented, to include physics of failure, highly accelerated life testing/highly accelerated stress screening, preventative maintenance determination and pit stop engineering. This analysis uses an Active Protection System (APS) to show that, when RAM is included in the Survivability Onion; both Survivability and RAM evaluations benefit; survivability assessments become more complete; RAM assessments are completed sooner; and ultimately, better systems are put into the hands of service members. As APS requirements are developed, it is important that they include the Materiel Availability Key Performance Parameter with associated Reliability and Ownership Cost Key System Attributes. When evaluating an APS (or any system) the independent evaluator team members need to integrate and discuss the impacts of the capabilities and limitations they observed with each other to ensure that the deficiencies are properly addressed in the reports.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
APS	Active Protection System
ADT	Administrative Downtime
A_O	Operational Availability
A_M	Materiel Availability
APS	Active Protection System
AR	Army Regulation
ATEC	Army Test and Evaluation Command
CFE	Contractor Furnished Equipment
CIA	Critical Item Analysis
CMT	Corrective Maintenance Time
DA PAM	Department of the Army Pamphlet
DAU	Defense Acquisition University
DoD	Department of Defense
EFF	Essential Function Failures
FCA	Failure Compensation Analysis
FDSC	Failure Definition/Scoring Criteria
FMEA	Failure Modes Effect and Analysis
FMECA	Failure Modes Effects and Criticality Analysis
FRACAS	Failure Reporting, Analysis, and Corrective Action System
FSR	Field Service Representative
GFE	Government Furnished Equipment
HALT	Highly Accelerated Life Testing
HASS	Highly Accelerated Stress Testing
HMMWV	High Mobility Multipurpose Wheeled Vehicle
HQ	Headquarters
HQDA	Headquarters Department of the Army
IED	Improvised Explosive Device
ILS	Integrated Logistics Support
IPT	Integrated Product Team

JCIDS	Joint Capabilities Integration and Development System
KPP	Key Performance Parameter
KSA	Key System Attribute
LDT	Logistics Downtime
MANPRINT	Manpower and Personnel Integration
MLDT	Mean Logistics Downtime
MMBEFF	Mean Miles Between Essential Function Failure
MMT	Mean Maintenance Time
MRAP	Mine Resistant Ambush Protected
MRBF	Mean Rounds Between Failures
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
MTBSA	Mean Time Between System Aborts
MTTR	Mean Time To Repair
NEFF	Non-Essential Function Failure
OIF	Operation Iraqi Freedom
OTA	Operational Test Agency
PMT	Preventative Maintenance Time
PoF	Physics of Failure
RAM	Reliability, Availability, and Maintainability
RPA	Risk Priority Analysis
RPG	Ruchnoy Protivotankovy Granatomyot (translation: hand-held antitank grenade launcher)
SA	System Abort
TEMP	Test and Evaluation Master Plan
TIR	Test Incident Report
TRADOC	Training and Doctrine Command
USFOR-A	United States Forces-Afghanistan

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I. INTRODUCTION

A. SYSTEM EVALUTIONS

As a program progresses through the acquisition process, the Operational Test Agency (OTA) tests and evaluates the effectiveness, suitability and survivability of the system. The evaluations for these systems are completed by multiple action officers with their own areas of expertise. For example, at the Army Test and Evaluation Command (ATEC, 2010), an Acquisition Category (ACAT) I program may have seven different people writing the OTA Evaluation Reports. Under effectiveness, there are typically performance and safety evaluators; under suitability, there are typically Reliability, Availability, and Maintainability (RAM), Integrated Logistics Support (ILS), and Manpower and Personnel Integration (MANPRINT) evaluators; and under survivability there are typically ballistics and non-ballistics evaluators. Each section of the report is written independently of the others, and then combined into one report. The issue is that each independent evaluation can have an affect the on the other systems. Service members may not be able to effectively complete their missions if reliability or training is poor. Soldier survivability is at risk if a system cannot effectively mitigate threats. It is important that these interactions are discussed and included in the overall evaluation.

B. FOCUS

This paper focuses on the interaction of RAM and Survivability and why RAM should be included in the Survivability Onion. Active Protection Systems (APS) will be used as an example to explore the interdependency and importance of RAM to survivability. The research will demonstrate how APS reliability enhances system dependability, APS maintainability enhances trust, and APS availability enhances survivability. The analysis will illustrate how RAM and the Survivability Onion (Deitz, Reed, Klopcic & Walbert, 2009)interconnect and complement each other by using examples of an APS, and other Army systems.

Survivability evaluations and RAM evaluations mutually benefit when they are done in concert. Survivability evaluations benefit by having the ability to assess how a system's survivability will be affected over time, and RAM evaluations benefit by having the ability to assess how the suitability of the system will affect Soldier Survivability. Survivability evaluations benefit because systems under test are typically fresh off the assembly line and have not been subjected to the operational environment due to schedule constraints (i.e., the Survivability evaluation must be done before the system is fielded). RAM evaluations benefit because systems under test typically do not have service member (i.e., soldiers, sailors, airmen, or marines) involvement until operational tests, and by that point, system designs become much more difficult and costly to change to increase the system's suitability. Therefore, this analysis will use an APS to show that when RAM is included in the Survivability Onion; both Survivability and RAM evaluations benefit; Survivability assessments become more complete; RAM assessments are completed sooner; and ultimately, better systems are put into the hands of our service members.

II. SURVIVABILITY

A. SURVIVABILITY

Survivability can be, and is, defined many ways. However, for the extent of this Project, "Survivability" will be defined as:

> The total capability of a system (resulting from the synergism among personnel, materiel, design, tactics, and doctrine) to avoid, withstand, or recover from damage to a system or crew in hostile (man-made or natural) environments without suffering an abortive impairment of its ability to accomplish its designated mission. (Deitz et al., 2009, p. 2).

Basically, Deitz et al. (2009) introduces two important aspects of Survivability: The Survivability Onion, and The Operational Environment.

1. The Survivability Onion

The Survivability Onion is a symbolic title that illustrates the different layers, or opportunities, a platform has to mitigate the effects of a given threat. The "layers" of the Survivability Onion are illustrated in Figure 2, below developed by Dr. David Wilkes (2007):

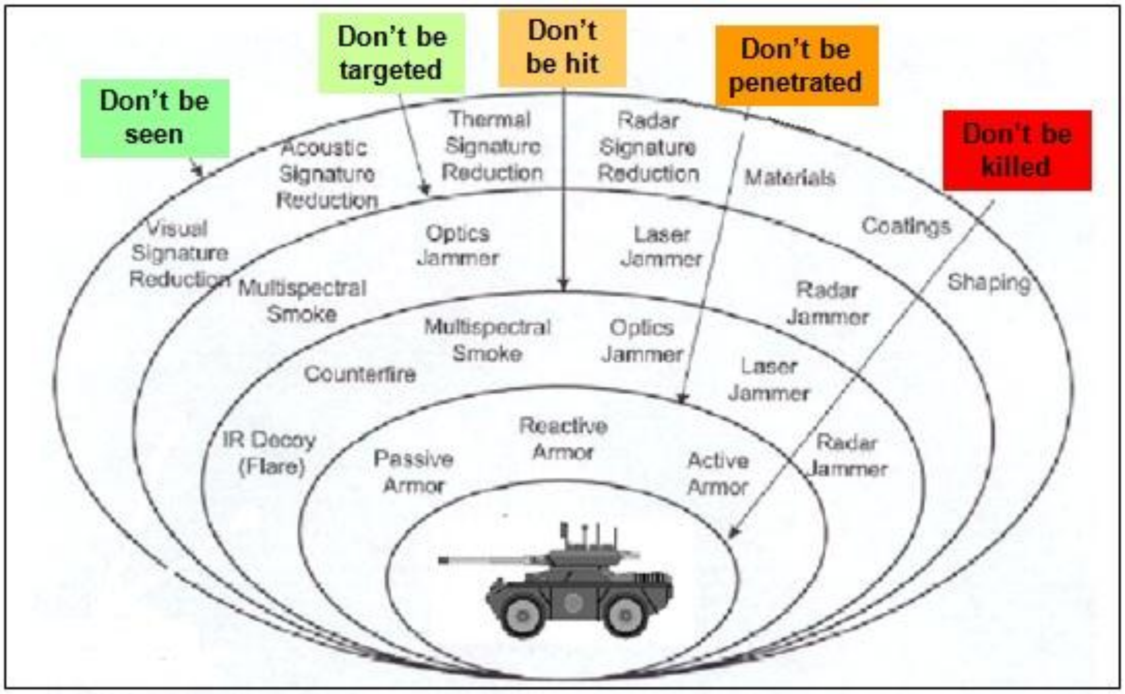

Figure 1. The Survivability Onion (From Wilkes, 2007)

The Survivability Onion can also be described as: Don't be seen. If you are seen, don't be targeted/acquired. If you are targeted/acquired, don't be hit. If you are hit, don't be penetrated. If you are penetrated, don't be killed.

Consider at the onion from the perspective of the unfortunate combat system in the middle of Figure 1. Each layer of the survivability onion shows how the vehicle can partially or completely mitigate a potential threat. The first layer of the onion is "Don't be seen," or a threat is on the lookout and the vehicle doesn't want to be spotted. At this layer, the vehicle can hide in a forest, apply camouflage, the crew can dig a hole that hides it up to the turret, the engine can be turned off to place the vehicle into silent watch, or take some other actions to not be spotted.

The second layer is "Don't be targeted," or a threat has now at least partially seen the vehicle and is aiming at it trying to acquire for engagement. At this layer, the vehicle can generate smoke obscuring itself, fire lasers damaging optics, distract an aggressor with loud noises, fire weapons at the threat, move rapidly, or take some other actions to not be targeted.

The third layer is “Don’t be hit,” or a threat has at least partially seen and acquired the vehicle and is now engaging. At this layer, the vehicle can fire flares, move to dodge the incoming round, engage the threat with weapons, or some other actions to not be hit.

The fourth layer is “Don’t be penetrated,” or a threat has at least partially seen, acquired, and hit the vehicle, and now we’re trying to mitigate the threat’s weapon effects. At this layer, the vehicle is depending on its armor, and other protective subsystems, to protect its crew and critical subsystems from any direct assaults.

The fifth, and final, layer is “Don’t be killed,” or a threat has at least partially seen, acquired, hit, and penetrated the vehicle, and now the threat is affecting the crew and subsystems within the vehicle itself. At this layer, the vehicle is depending on spall liners, compartmentalization, personnel protective gear, fire extinguishers, and other protection measures to keep the crew from being injured, critical subsystems being damaged, and the vehicle’s mission being affected.

This concept basically breaks an engagement down into different steps where each step allows the system the ability to reduce, or mitigate, the effects from a given threat. The idea is that the system/user should be able to maintain sufficient effectiveness to complete the mission after an event has occurred. The events occur within the confines of The Operational Environment.

2. The Operational Environment

The Operational Environment is any environment where the system is expected to perform its intended missions, and these environments contain various threats that may act upon the system. The threats may be legion, and varied, but are typically detailed in the system’s requirements documents as well as the System Threat Assessment Report, which is typically produced by intelligence sources. There are several organizations that can put together threat assessments, but the National Ground Intelligence Center’s Anti-Armor Analysis Program, based out of Charlottesville, Virginia, typically provides Army system threat assessments.

Afghanistan is one example of an operational environment. The military has collected a significant amount of data about Afghanistan and the insurgent groups in the area and their military tactics. For instance, we know that the area around Kandahar is typically dusty and hot, and that opposing forces may use Soviet era weaponry that was left in the area while the Soviets withdrew from Afghanistan between the middle of 1988 and early 1989. This gives us a picture of the operational environment around Kandahar and with this knowledge; we can better prepare a system to survive in that environment.

III. ACTIVE PROTECTION SYSTEM

A. ACTIVE PROTECTION SYSTEMS

An APS will likely be found on the military platforms of the future. The Department of Defense (DoD) is currently engaged in Afghanistan, but is in the process of retrograding the forces employed in the region. The DoD is evaluating the future of the forces as these forces come home. Currently several platforms use bulky armor systems to mitigate the Operational Environment's threats. Because of the additional weight, dimensions, and added transportation, these armor systems place a massive strain on logistic systems and lead to higher life cycle costs.

The most survivable systems for the current operational environment (i.e., Afghanistan) tend to be gargantuan. Heavy armor was the most typical solution after analyzing the operational environment through the lens of the Survivability Onion, with an understanding of the tactics being used by insurgent groups. First, the tactics typically used by insurgent groups, especially against vehicle convoys, are not direct force-on-force engagements. They prefer to attack quickly and with as mines and improvised roadside explosives operated by few or no people. This is why the under-vehicle Improvised Explosive Device (IED) and Ruchnoy Protivotankovy Granatomyot (RPG) (English translation: hand-held antitank grenade launcher) have become insurgent weapons of choice. These devices allow them to be hidden from view and catch unsuspecting coalition forces by surprise.

Consider the Survivability Onion, and envision a surprise attack scenario where an insurgent group, with a RPG, is waiting for a coalition convoy to pass by unaware of the threat. . The insurgent group is already circumventing the "Don't be seen" and "Don't be targeted" levels of the Survivability Onion. Therefore, the convoy is already put at a disadvantage and, assuming the insurgent group has received adequate training or is moderately experienced with the RPG (and that our example convoy does not have APSs), the insurgent group has a relatively high probability of hitting a vehicle in our example convoy. The vehicle example now has lost three layers of the Survivability

Onion ("Don't be seen," "Don't be targeted," and "Don't be hit") because current convoys cannot effectively control being seen or targeted, and the insurgent group was adequately experienced with the RPG and had the element of surprise on their side.

The vehicle, in this example, can be any platform. It can be an Abrams tank, a Bradley Fighting Vehicle, a ¾ Ton truck, a Jeep, or a Toyota pickup. However, assume for a moment it is a Stryker (armored, wheeled platform). The Stryker that has been struck in our example by the RPG round, is now "seeing" the threat at the "Don't be penetrated" level of the Survivability Onion. The RPG round is designed to penetrate the vehicle's protective armor to cause injuries to the crew and damage to crucial subsystems, so the theoretical Stryker's armor is now tasked with stopping the RPG round and prevent injuries and damage. Therefore the Stryker's armor package needs to be designed in such a way that it prevents or mitigates the penetration of a RPG threat.

Typically, the way penetrating threats are mitigated are through geometric and bulk solutions. Basically, if you angle an armor plate, or increase its thickness, you're causing a penetrating threat to have to penetrate more armor to achieve penetration. A good example of this is the front glacis on the Abrams (the angled parts on the front of the turret on either side of the cannon as noted on Figure 2), where the angle and bulk of armor plate makes it harder for penetrating threats to penetrate the armor.

Figure 2. Abrams Front Glacis (After http://en.wikipedia.org/wiki/File:Abrams-transparent.png)

However, there is a tradeoff, the increased armor also increases weight to the platform (our example above of the Abrams is a very massive platform which, fully loaded, can weigh in excess of 70 tons). The more weight added to a platform increases it's logistical challenges.

The added weight impacts logistics in several ways: transporting the systems to the theater of operations is more difficult and costly; the systems require more powerful engines and consume significantly more fuel; and the armor weight can stress suspension and braking systems, adding to the total logistics burden.

One of the most taxing missions for the United States Forces Afghanistan (USFOR-A) is moving these massive platforms from place to place and decision makers must make difficult decisions. The Army alone, as of June 2013, had "about $25 billion in military equipment sitting in Afghanistan," but not all of that equipment will be coming home; the "Army has only decided to ship back 76 percent of its equipment, which will cost $2 to $3 billion just in transportation" (Fisher, 2013, para.4). These transportation costs are huge, and are so partially because of armor packages' weight.

Afghanistan is a landlocked country that borders six other nations (Pakistan, Iran, Turkmenistan, Uzbekistan, Tajikistan, and China), so to move a massive platform, you basically have two options; over land, or by air. The geography of the Hindu Kush mountain range and arid deserts of Afghanistan can slow over land deliveries, so air is usually the transportation method of choice. However, platforms with massive armor packages are difficult to fit into the cargo aircraft typically used by the military while still allowing the airplanes to get off the ground at all. This causes more trips to be taken and the price to go up, adds to logistic backlogs, and headaches for logistics staff.

These behemoth systems do effectively save lives in the current operational environment, but they are quickly becoming unattractive in our current fiscal environment. What are needed are systems that will cause less life cycle burdens, while providing similar, or better, levels of protection. Therefore, APS are poised to become essential in the near future.

1. What They Are Designed to Do

APS are designed to actively protect the systems they are integrated upon. They constantly scan the operational environment to detect potential threats that could damage the system they are integrated with and mitigate those threats.

2. How They Work

The currently deployed armor packages are designed to work at the "Don't be penetrated" level of the Survivability Onion. However, an APS is designed to work at the "Don't be targeted" or "Don't be hit" level, because they typically interact with the threat some distance away from the platform itself. These systems attempt to expand the protective boundaries around the host platform, and increased distance from a threat event typically increases survivability.

One example of an APS is the Iron Curtain. The Iron Curtain is shown in Figure 3. (The Iron Curtain is the horizontal bar offset from the roofline of the base platform.)

Figure 3. Iron Curtain APS (From Defense Update, 2013)

The Iron Curtain uses electronic sensors and defeat mechanisms to sense, and mitigate, incoming threats. The procession below shows how this sense and defeat process is supposed to work. Note: This is not an endorsement of the Iron Curtain system, or any specific system developer, it is simply being used as an example of an APS.

Figure 4. Iron Curtain Sensing, Striking, and Mitigating a RPG Threat (From Defense Update, 2013)

Figure 4 shows three panes of a RPG threat engagement by the Iron Curtain APS. The engagement is demonstrated with the threat coming in from the left side of the frame and being fired at a simulated vehicle platform. The Iron Curtain is hung, as shown above, from the "roofline" of the platform, which means that the plate hanging below the Iron Curtain is the simulated platform's base armor, and behind that plate (to the right of the frame) is the "crew compartment" of the simulated platform. The first pane shows the RPG threat coming in from the left side; the Iron Curtain has sensed the threat and triggered its defeat mechanism. The second pane shows the defeat mechanism firing at, and striking, the RPG threat. The third pane shows that the RPG threat has been mitigated because the simulated base armor has not been penetrated (we would be able to see visible ejecta to the right of the simulated base armor showing that the threat has gotten past the Iron Curtain, through the base armor and into the "crew compartment").

3. Why the DoD is interested

An APS can be a powerful ally in the future of constrained program budgets.

a. Weight Savings

An APS can weigh orders of magnitude less than a Rolled Homogenous Armor (RHA) package capable of defeating the same threat. The physical size of these two systems can lead to efficient production systems completing APS production/installation runs quicker than they could a comparable RHA package.

The Iron Curtain in Figure 4 is about three feet long, weighs less than 200 pounds, and let's assume for this calculation the defeat mechanism is effective for three feet below the Iron Curtain. That gives us a three foot by three foot area in which the Iron Curtain can effectively mitigate a RPG threat. Now, assume that threat is a typical RPG threat, like the RPG-7V (state of the art circa 1961) which has a RHA penetration capability of a little over 10 inches (0.833 feet) (http://en.wikipedia.org/wiki/RPG-7). The density of RHA is approximately 485 pounds per cubic foot (http://www.alternatewars.com/BBOW/Ballistics/Armor_Material.htm), so the weight of a RHA plate that would have at least the capability of our example Iron Curtain would be:

$$3 \text{ ft} \times 3 \text{ ft} \times 0.833 \text{ ft} \times 485 \text{ lb/ft3} = 3640 \text{ lbs}$$

This example shows that our example Iron Curtain, which weighs less than 200 lbs, has similar capabilities against our example RPG-7V as a 3,640 lb RHA plate. That is more than a 94% weight savings in this example.

b. Logistic Burden

The Iron Curtain versus RHA Plate example above can also show us the logistic burdens of these two solutions. The Iron Curtain, at less than 200 pounds, could be effectively transported short distances by a small team of personnel. The RHA Plate on the other hand, at 3,640 pounds, isn't moving without at least a forklift present for assistance.

For our example Iron Curtain system, which we already assumed is three feet long, has a cross section of about one foot; that would make the volume of the system approximately three cubic feet. Also, remember our example RHA Plate with the comparable protection is 7.5 cubic feet (3 ft x 3 ft x 0.833 ft). That means the example Iron Curtain is 60% smaller, and remains 94% lighter, than the comparable RHA Plate. Those space and weight savings mean that fewer trucks, or planes, are needed to transport a comparable protection package which means less fuel is consumed and less time is spent in transit, leading to cost savings throughout the logistic chain.

4. Why the DoD is apprehensive

However, these systems do have drawbacks.

a. Complicated

APS can be complicated. Their defeat mechanism will typically be controlled through computer software that needs to measure, understand, and act upon collected sensor data with extreme reliability. The system will also not have very much time to correctly figure whether or not its sensors have found a genuine threat that requires action. Threats may only be in the APS's effective defeat zone for milliseconds.

b. Trust

An APS will suffer from trust issues in the near future. Service members are used to large armor systems protecting them from threats in the operational environment. When they are asked to trust this new system with markedly less base armor, there will likely be an adjustment period. This also means that any APS must have the same, or greater, protection that a comparable RHA package. If the APS cannot protect a platform's crew better than what service members are accustom to, they will begin to question why the APS has been tasked with their protection.

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IV. SUITABILITY

A. SUITABILITY TEST AND EVALUATION OVERVIEW

During the acquisition process, a system goes through multiple tests and evaluations. Suitability test and evaluation starts with the defining of requirements by the combat developer. Once the requirements are established the testing is planned and should be based on the needs of the evaluator. The types and lengths of tests will depend upon the system requirements and will be described in the system's Test and Evaluation Master Plan (TEMP). For instance, a helicopter will need to be flown for an evaluator determined number of hours while a vehicle will need to be driven for a determined number of miles. These hours and miles will be accumulated through both developmental and operational testing. Also, a logistics demonstration will be completed. As defined by the DAU glossary, a logistics demonstration is used to evaluate the adequacy of the system support package and ensure the user unit has the logistical capability to achieve initial operational capability. (https://dap.dau.mil/glossary/)

1. Test Incident Reports

Test Incident Reports (TIRs) are required to be collected at all test events in the TEMP in accordance with Army Regulation (AR) 73-1: Test and Evaluation Policy (Headquarters Department of the Army (HQDA), 2006). Per AR 73-1 (HQDA, 2006, p.33), "a TIR describes the minimum essential data for test incidents as they occur, their respective corrective actions and status, and other test information." Specifically, a TIR includes when the incident occurred, an incident description of what actually happened and the function lost, how it was fixed, how long it took to fix, who performed the maintenance, spare parts usage, and when it was returned to service.

2. Failure Definition/Scoring Criteria

Throughout and at the conclusion of the test, dependent upon the test length and number of TIRs,, the RAM Integrated Product Team (IPT) convene to determine the TIR scores. The RAM IPT scoring conference members consist of a representative from the materiel developer (Program Manager), combat developer (Training and Doctrine Command (TRADOC)), and independent evaluator (ATEC). A TRADOC written Failure Definition/Scoring Criteria (FDSC) is used as guidelines to score the TIRs that were generated during the event. Per Department of the Army Pamphlet (DA PAM) 70-3 (HQDA, 2009, p.88), "The FDSC defines the required functionality and allowable levels of degradation (in other words, what constitutes a reliability failure) and establishes a framework for classifying and charging test incidents."

According to the Guidelines for Developing Reliability Failure Definition and Scoring Criteria (Headquarters (HQ) TRADOC Combat Developments Engineering Division, 1995), the FDSC is split into 2 major areas, the failure definition and scoring criteria. As part of the failure definition portion, the FDSC establishes the essential functions of the system (for example, the essential functions of a cargo helicopter would be fly, communicate, navigate, survive, sling load, and internal load). The purpose of the failure definition is to ultimately describe, from a user's perspective, degraded and unacceptable performance which, when evidenced by component or subsystem malfunction, is considered a failure (HQ TRADOC, 1995, p2).

Primary failure categories are Non-Essential Function Failure (NEFF), Essential Function Failure (EFF), and System Abort (SA). An EFF is generally described as a failure or malfunction causing degradation below an established level or causing complete loss of an essential function(s). If loss or degradation of the function(s) results in immediately removing the system from service, the failure is not only an EFF, but also an SA. An SA generally precludes ability to enter into use or to continue in use. Take for instance you are on your way to work and your radio stops working. This would be scored as a NEFF because your radio is not required for your commute. However, if your wheel falls off, it would be an EFF and more specifically a SA, as you would no longer be able to drive your car.

The second part of the FDSC is the scoring criteria. The scoring criteria should outline a specific process for classifying test events into proper categories and for charging failures to appropriate causes. (HQ TRADOC, 1995, p7) Classification of an event is made based upon the event's impact on system operational performance. Primary classification categories are: No Test, Non-Failure, and Failure. Figure 5 depicts an example of the scoring process and what type of event falls in each category.

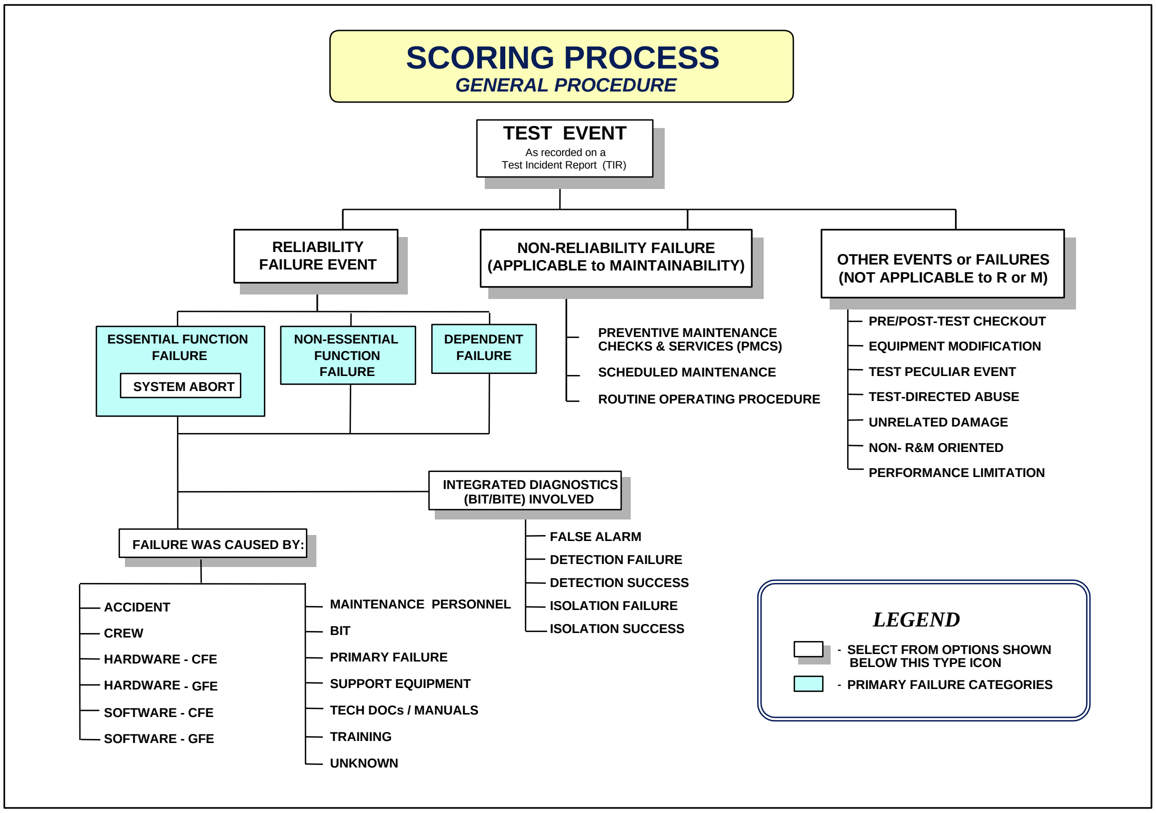

Figure 5. Sample Scoring Process (From HQ TRADOC, 1995, p8)

Following through the scoring process, the next step is assigning chargeability, which is what caused the failure to occur. Typical chargeabilities are Contractor Furnished Equipment (CFE) hardware and software, Government Furnished Equipment (GFE) hardware and software, crew/operator, maintenance personnel, technical documentation/manuals, training, support equipment, and unknown.

After the TIRs have been scored, the independent evaluator assesses the reliability, availability, and maintainability of the system.

3. Sustainment Key Performance Parameter (KPP)

Key Performance Parameters (KPPs) are defined in the Defense Acquisition University (DAU) glossary (https://dap.dau.mil/glossary/) as, "Those attributes or characteristics of a system that are considered critical or essential to the development of an effective military capability and that make a significant contribution to the characteristics of the future joint force." DoD has deemed certain KPPs mandatory under specific conditions. Among these, the Sustainment KPP is required for all Acquisition ACAT I programs requiring a materiel solution; for ACAT II and below programs, the sponsor will determine the applicability of this KPP. The Sustainment KPP has three elements, an Availability KPP made up of two components, Materiel Availability (A_M) and Operational Availability (A_O) and two Key System Attributes (KSAs), Ownership Cost and Reliability. These are further defined below. (JROC, 2012)

B. RELIABILITY

1. Definition

According to the Defense Acquisition University (DAU) (https://dap.dau.mil /glossary/), reliability is the probability that an item will perform in a satisfactory manner in its intended operational environment over time, without failure. An item's reliability depends on how well it is designed, the quality of the materials used, the quality of the manufacturing process, and it proper operational use in its intended operating environment. The failure rate is used to measure reliability, which refers to the frequency with which a system fails over time. In simplest terms, reliability is the ability of a system and its parts to perform the mission without failure, degradation, or the demand on the support system under a prescribed set of conditions (https://dap.dau.mil/acquipedia).

2. Reliability Metrics

In the Test and Evaluation of System Reliability Availability Maintainability-A primer, Colin, Lilius, and Tubbesing (1982) define Mean Time Between Failures (MTBF) as the total functioning life of a population of an item during a specific measurement interval, divided by the total number of failures within the population during that interval. MTBF can be interpreted as the expected length of time a system will be operational between failures. The definition is true for time, cycles, miles, events, or other measure-of-life units. These various measure-of-life units permit the MTBF term to be tailored to the reliability requirements of a specific system. Some examples of this tailoring are: a gun may have a Mean Rounds Between Failures (MRBF) of 10,000 rounds, a HMMWV may have Mean Miles Between Essential Function Failure (MMBEFF) requirement of 1,000 miles, and an unmanned aircraft may have a Mean Time Between System Aborts (MTBSA) of 100 flight hours.

Failure rate is defined as the number of failures of an item per measure of life unit (e.g., cycles, time, miles or events as applicable) (Colin, et al., 1982). This measure is more difficult to visualize from an operational standpoint than the MTBF measure, but is a useful mathematical term, which frequently appears in many engineering and statistical calculation. It is the reciprocal of the MTBF measure.

Mission Reliability is the probability that a system will perform mission essential functions for a period of time under the conditions stated in the mission profile (Colin, et al., 1982). Mission reliability for a single shot type of system, i.e., a missile, would not include a time period constraint. A system with high mission reliability has a high probability of successfully completing the defined mission. Measures of mission reliability address only those incidents that affect mission accomplishment. For example, a helicopter may have a mission reliability requirement of an 85% probability of completing a 5 hour mission without experiencing an essential function failure.

C. MAINTAINABILITY

1. Definitions

As defined in the DAU Lifecycle Logistics 101 Course Materials (DAU, 2013), maintainability pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions. It is the ability of an item to be retained in, or restored to, a specific condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.

a. Logistics Footprint

A logistics footprint is a term that includes personnel, supplies/equipment, and real property (land and facilities) necessary to deploy and sustain a weapon system (DAU, 2013). A large logistics footprint can adversely affect how quickly a military force can deploy and how effectively it can be sustained

If logisticians are spending too much time coordinating with the various organizations on acquiring, packaging, shipping and storing more material than will be utilized by service member needs, that spells trouble (i.e. higher operational costs).

Measuring a system's logistics footprint requires consideration of many elements: personnel (government and contractor), inventory, support and test equipment, facilities, transportation assets, and real estate. The following are examples of how a logistics footprint can be measured: weight (total weight of deployable consumables, support equipment, energy (fuel, oil, etc.), and spares); personnel (total number of personnel (government and contractor) in the deployed area required to transport and sustain the weapon system); and volume (total volume (usually measured in cubic feet) of deployable consumables, support equipment, fuel, and spares (DAU, 2013).

The size of the logistics footprint is driven largely by the system's reliability and maintainability. If a system has unreliable components, you will need more spares, maintenance personnel, and support equipment to maintain the system. Designing-in reliability is the best approach to minimizing the logistics footprint.

b. Types of Maintenance

Preventative maintenance is defined in the DAU glossary as: All actions performed in an attempt to retain an item in a specified condition by providing systematic inspection, detection, and prevention of incipient failures. For example, you replace your brake pads when they are worn beyond a specific level. Scheduled maintenance is preventive maintenance performed at prescribed points in the item’s life. For example, every 6,000 miles, you change the oil in your car.

Corrective Maintenance (also known as unscheduled maintenance) is defined in the DAU glossary as: all actions performed because of a failure to restore an item to a specified condition. Corrective maintenance can include any or all of the following steps: localization, isolation, disassembly, interchange, reassembly, alignment, and checkout. Corrective maintenance can be as simple as resetting a computer or as complex as replacing an engine.

2. Maintainability Metrics

Maintainability can be assessed using Mean Time To Repair (MTTR), which is calculated by dividing the total corrective maintenance time by the number of repair actions. Corrective maintenance time includes diagnostic time, time to repair, and time to verify the repair. Mean Maintenance Time (MMT) is calculated by adding the preventive and corrective maintenance time and dividing by the sum of scheduled and unscheduled maintenance events during a stated period of time. Another useful maintainability metric is Mean Time Between Maintenance (MTBM), which includes preventative maintenance in addition to corrective actions. It is calculated by dividing the operating time by the total number of maintenance actions.

One example of these metrics would be a fleet of 100 HMMWVs that, on average, are in the shop once a month, and the mechanics typically can get all the preventative maintenance done in an hour, but this month some of these HMMWVs (let's assume one in ten) have been having trouble with their engine requiring an engine swap-out that takes two hours. For this example, assuming a 30 day month and 24 hour operations for each truck when they're not in the shop, our MTTR, MMT, and MTBM are as follows:

MTTR: 2 hours corrective maintenance/ 1 engine= 2 hours

MMT: (100 trucks * 1 hour [preventative maintenance] + 10 trucks * 2 hours [corrective maintenance] / 110 total maintenance actions = 1.09 hours

MTBM: (90 trucks * (29 days + 23 hours) + 10 trucks * (29 days + 21 hours)) / 110 total maintenance actions = 653.45 hours = 27 days and 5.45 hours

The lower that MTTR and MMT are, and the longer the MTBM is, the more time a system can be in the hands of the users and the more time a user has around a system the more familiarity is built with that system.

D. AVAILABILITY

1. Definitions

Per Colin, et al. (1982), Availability is a measure of the degree to which an item is operable and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time. It is defined as uptime divided by total system time, where total system time is uptime plus downtime. Colin et al. (1982) further breaks down availability into three metric types: Inherent, Achieved, and Operational Availability. A fourth type (Materiel Availability) was more recently established in accordance with the Joint Capabilities Integration and Development System (JCIDS) Manual (2012).

2. Availability Metrics

Inherent availability reflects the designed-in levels of readiness if everything works as predicted and all required logistics support is immediately available. It is a combination of the "inherent" design characteristics of reliability and maintainability. It is measured as MTBF divided by the sum of MTBF and MTTR.

Achieved Availability is availability of a system with respect to operating time and both corrective and preventive maintenance. It may be calculated as MTBM divided by the sum of MTBM and MMT.

Operational Availability (A_O) is the degree to which one can expect a piece of equipment or weapon system to work properly when it is required, that is, the percent of time the equipment or weapon system is available for use. A_O represents system "uptime" and considers the effect of reliability, maintainability, and mean logistics delay time. It is the quantitative link between readiness objectives and supportability. Figure 1 shows the inputs which are used to calculate the $A_{O.}$

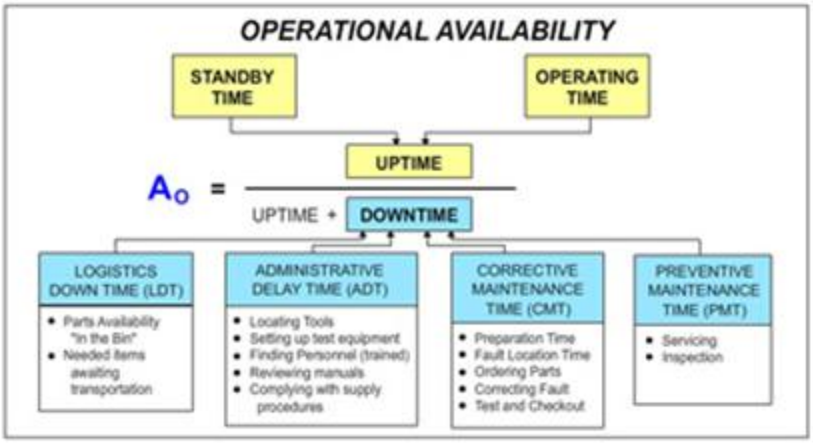

Figure 6. Operational Availability (From DAU , 2013)

A_O may also be calculated by dividing MTBM by the sum of the MTBM, MMT, and Mean Logistics Delay Time (MLDT), that is:

$$A_O = MTBM / (MTBM + MMT + MLDT),$$

Where MLDT is defined as the average time a system is awaiting maintenance and generally includes time for 1) Locating parts and tools, 2) Locating, setting up or calibrating test equipment, 3) Dispatching personnel 4) Reviewing technical manuals, 5) Complying with supply procedures, and 6) Awaiting transportation. The MLDT is largely dependent upon the logistics support structure and environment.

Materiel Availability (A_M) is defined as the measure of the percentage of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given time, based on materiel condition. It addresses the total population of end items planned for operational use, including those temporarily in a non-operational status once placed into service (such as for depot-level maintenance). The total life cycle timeframe, from placement into operational service through the planned end of service life, must be included. (JROC, 2012).

A_M requires comprehensive analysis of the system and its planned use, including the planned operating environment, operating tempo, reliability alternatives, maintenance approaches, and supply chain solutions. Materiel Availability is primarily determined by system downtime, both planned and unplanned. It requires the early examination and determination of critical factors, such as the total number of end items to be fielded and the major categories and drivers of system downtime. A_M is expressed as the Number of Operational End Items divided by the Total Population.

Ownership Cost provides balance to the sustainment solution by ensuring that the operations and support (O&S) costs associated with Availability are considered in making decisions (https://dap.dau.mil/acquipedia/). For consistency and to capitalize on existing efforts in this area, the Cost Analysis Improvement Group O&S Cost Estimating Structure will be used in support of this KSA (http://www.dtic.mil/pae/). As a minimum the following cost elements are required: 2.0 Unit Operations (2.1.1 (only) Energy (fuel, petroleum, oil, lubricants, electricity)); 3.0 Maintenance (All); 4.0 Sustaining Support (All except 4.1, System Specific Training); 5.0 Continuing System Improvements (All). The O&S value should cover the planned lifecycle timeframe, consistent with the timeframe used in the Materiel Availability metric (https://dap.dau.mil/acquipedia/). Development of the Ownership Cost metric is a program manager responsibility.

V. APS AVAILABILITY ENHANCES SURVIVABILITY

A. WHY RAM BECOMES ESSENTIAL IN SURVIVABILITY ONION WHEN APS ARE USED

A fielded APS must be effective, because if the APS is not effective at mitigating the threats it is designed to mitigate, there are massive safety concerns with putting that APS into the field. However, even if an APS is effective, acceptance of these systems by men and women on the ground will still be essential for their success. Service members will need to be convinced to trust their lives to these systems and that is why Reliability, Maintainability and Availability of the APS will be so essential.

1. Reliability Enhances Dependability.

The more reliable a system is the more dependable it becomes. Reliability allows systems to be in use for more time in between mission aborts. Longer missions become feasible when higher reliability is achieved. These extended missions, without aborts, give users the perception that the system is more dependable.

The current perception is that the most dependable protection systems are the massive armor packages currently employed throughout the operational environment. These massive armor packages are tangible, and thought to be very dependable and will not “let you down” when you need them. Changing that perception will take time and success. (Wilson, 2004). Armor, being a physical barrier that you can see and feel, adds to its perception of being effective. The thicker the better, as long as you are not a logistician. The operational environment is fraught with instances, events, and effects that can quickly damage, or even destroy systems ill prepared for its challenges. For instance, systems that are used for littoral combat (like most Marine Corps system are designed for) will need to deal with the extreme corrosive effects from salt-water spray. To gain wide acceptance, an APS will need to be designed to take these destructive operational environments in stride and be survivable to their various effects. System reliability will suffer if the APS experiences an unacceptable amount of mission failures when emplaced in the intended operational environment, and a perception will quickly spread that the APS cannot be depended upon to protect the platform, or its crew.

2. Maintainability Enhances Trust.

- **New systems require new habits to be formed**.

There will be a learning curve with the new systems, including how to maintain these systems. The current plate armors are very simple to maintain. Just clean the plates if they're dirty, plug any holes where they appear, and replace the plates if they become too damaged.

An APS will take more time, patience, and experience to maintain. When an APS becomes dirty, personnel cannot just clean it off without considering how the cleaning procedures will affect the APS. Abrasive cleaners that were available to clean off armor plates, may damage sensitive APS components. Damaged components, especially if they are electronic, will also take different skills to repair. For instance, if an armor plate is damaged by small arms fire, maintainers may only need to paint the damaged section or plug a hole, but if an APS is damaged by small arms fire, especially if the sensors for the APS are damaged, maintainers may need to replace major components. There will also be software maintenance for an APS as well as hardware maintenance, which could lead to an increased training burden when these systems are first employed.

Any APS will have a software package that is essential for the system's threat response. Software is not necessary for armor plates to protect the system they are employed upon. So, these software suites will require maintainers to understand how to best maintain the software to maintain the protection provided by the APS. Also, given their electronic systems, an APS may be more susceptible to environmental factors in the operational environment than comparable armor plates. For example, an armor plate could be directly struck by lightning and arguably be unaffected, but an APS, and its electronic components, will likely be drastically affected from the same event.

- **Experience with the systems may quickly build, but will not be immediate.**

Learning curves and maintenance needs can lead to questions as to whether or not the APS is a necessary addition to the platform. There will be added workload to maintainers of an APS over their workload with a comparable plate armor package and questions may come up on whether or not this added workload is really making a difference. Regrettably, one of the quickest ways for a protection system to gain notoriety and trust is for users to see the protection system in action: a body armor is hit, but not penetrated; a fragmentary grenade goes off and fragments become lodged in a helmet, but the wearer is protected; or a threat is detected by an APS, but users witness the APS effectively responding to the threat. Another good example of this phenomenon is the spread of bar armors.

Bar armors were designed to counteract specific threats, but they were initially seen as a nuisance and counterproductive by some of the personnel that first received them. When they received their bar armor "upgrades," the personnel suddenly found they couldn't hang any of their gear off of the sides of their vehicle anymore, so they saw the bar armor as directly impeding their ability to complete their mission. However, as soon as the bar armor successfully defeated a threat, that hadn't been adequately defeated before, word quickly spread on how great the bar armor was and that everyone needed an add-on armor kit. Then the Army had a different problem on their hand: They couldn't get bar armors out fast enough. This bottleneck, and quick change in opinions, led to personnel fashioning their own bar armors out of whatever metal scraps they could find around themselves, and a configuration management nightmare. However, eventually, all of the bottlenecks were corrected and few vehicles leave the protective perimeter if they do not have some type of add-on armor (Wilson, 2004).

- **The old base armors will be viewed as trustworthy; APS need to build, and maintain, at least that same level of trust**.

The ability of the unit to maintain their APS with organic support will be essential in building, and maintaining, trust in the system. Personnel that have recently been deployed are familiar with the massive systems designed to protect them. (Merle2007). When they are suddenly presented with a much more agile system, they will be impressed, but they will be hesitant about the protection the system provides until they have enough experience to trust the system. One of the best ways to build trust is to be reliably effective over time, and this means that you will need a strong maintenance program. The goal will be to have a maintenance plan in place so the system can quickly be returned to service when there is a failure.

Achieving organic support, rather than the use of contractor Field Service Representatives (FSRs), as the primary mode of support is one way of gaining the units trust in the APS. FSRs are typically contractors employed by a system developer who deployed with gaining units to service a system during the initial deployment when there usually a lack of technical orders to repair the APS. t Many service members will likely view the APS as just a “black box” if Field FSRs are the main mode of support. This is what happened with the first jammers used in Iraq. The jammers were viewed as a “black box,” or a device that works without really understanding its function and capability. This environment was created because the FSRs were tying into the platform’s power and giving the crew inside a switch to turn the jammer on. The crew did not have full control over the jammer beyond that switch, and were sometimes skeptical about the function capability of the system. (Wilson, 2004, p. A.19).

Because a system was deployed without the logistics in place, service members did not understand the operational capability beyond the affixed warning labels when the jammers were first installed on vehicles. After a few years, and with more electronic warfare officers, and some industrious maintenance technicians, the military determined how the jammers functioned so that they could be repaired onsite without the FSRs’ help. This resulted in reduced wait times at the depot, and increased trust being on the system because of a better understanding functionally of the jammer, and how it affixed to their vehicle, that used to be a “black box.” (Wilson, 2004, p. A.19).

3. Availability Enhances Survivability

- **If the APS is not available then the system may not be survivable to threats.**

There conceivably, could be a platform that reduces weight, through removing armor plates, to the point where it would not be survivable against particular threats without the APS being effective. These weight savings will be paramount for increasing off-road agility, automotive performance, and vehicle reliability for future systems.

- **Base armor is reduced due to APS presence.**

Typically, armor plating becomes thicker and thicker as it is tasked to defeat ever more effective threats, because armor plating provides survivability at the "Don't be penetrated" level of the survivability onion as shown previously in the example of the Iron Curtain and comparable armor plate. Armor plating is typically the last line of defense, beyond possible spall liners, between a perforating threat and the platform's crew. Any reduction in armor plating can lead to an overall reduction in platform weight, which can lead to higher automotive agility and vehicular performance. This weight saving may also lead to better fuel consumption for like distances, could make logistic footprints smaller, and could result in better reliability of suspension components. These benefits, and more, are the main reasons an APS would be used in lieu of added armor.

- **That system will not move if the APS is not available.**

When a platform's base armor is reduced for economic and performance reasons, and an APS is emplaced to boost the survivability of the system against operationally relevant threats, availability of that APS will mean survivability of the platform in the eyes of decision makers. This actually applies for most survivability upgrades, but one of the most recent is the fielding of Mine Resistant Ambush Protected (MRAP) vehicles early in Operation Iraqi Freedom (OIF).

The High Mobility Multipurpose Wheeled Vehicle (HMMWV) was the prevalent mode of transportation for ground troops before OIF, because they were the most trusted form of ground transportation at the time. However, the insurgents used this knowledge against the HMMWV, and emplaced underbody threats to exploit the

HMMWV's light armor. The underbody threats were so effective that personnel and materials were difficult to move anywhere across the country. (Merle, 2007, p. D.1.) The MRAP vehicles were designed, or bought, and used as the main mode of ground transportation through areas where underbody threats were likely. The MRAP vehicles became so effective at counteracting underbody threats (when compared to the HMMWV), that decision makers decided that HMMWVs were not allowed to leave bases and were confined to protective enclosures. No one left their base on the ground if they were trying to leave in a HMMWV. In short: A ground mission may not be run if a MRAP vehicle was not available to run it.

The same will become true in the future with a platform that depends on an APS. That platform may not be allowed off base if the APS it depends on for protection is not available.

B. MAKE IMPROVEMENTS TO RELIABILITY AND MAINTAINABILITY AND SURVIVABILITY WILL IMPROVE

By increasing the uptime (reliability improvements) and decreasing downtime (maintainability improvements), the availability of a system will improve. By improving the availability, the survivability will, in turn, also improve as long as the APS systems are effective.

1. Reliability Improvements

According to the Army's Center for Reliability Growth (presentation slides from Reliability Short Course, July 2010), the following are some ways to improve reliability that can be applied to the development of an APS:

- Approach reliability by designing it in rather than only testing it in, with high-level and continuous focus on reliability improvement
- Understand critical loads and stresses, even at component level
- Conduct thermal and vibration analyses to address potential failure mechanisms/sites
- Conduct low-level testing early in development to precipitate failures and improve design

- Conduct accelerated life testing for specific failure mechanisms and identify and implement corrective actions

When potential failure modes are found early in the development of a system, there is usually time and funding to fix these issues prior to production. By using Failure Modes Effect and Analysis (FMEA)/Failure Modes Effects and Criticality Analysis (FMECA) and employing a Failure Reporting, Analysis, and Corrective Action System (FRACAS), the contractor will be able to track the failed components and implement fixes prior to production and fielding. The contractor can also perform Highly Accelerated Life Testing (HALT)/ Highly Accelerated Stress Screenings (HASS) or Physics of Failure (PoF) analysis in order to surface the failure modes sooner.

a. FMEA/FMECA

The FMEA/FMECA is a reliability evaluation/design technique which examines potential failure modes within a system and its equipment, in order to determine the effects on equipment and system performance (https://dap.dau.mil/acquipedia). Each mode is classified according impact on mission success and safety to personnel and equipment. It should be noted that the FMECA is composed of three separate analyses, the Failure Mode and Effects Analysis (FMEA), the Criticality Analysis (CA) and Risk Priority Analysis (RPA), and Critical Item Analysis (CIA) and Failure Compensation Analysis (FCA) (DoD, 2013).

On its own, the FMEA aids in: determining the effect of each failure mode on performance; root cause identification and development of corrective actions; investigation of design alternatives; development of test methods and troubleshooting techniques; qualitative reliability and maintainability analyses; locating single point failures. By adding the Criticality Analysis (to include the RPA, CIA, and FCA), the FMEA becomes a FMECA which additionally aids in: providing data for developing the Reliability Block Diagram and Fault Tree Analysis; qualitative safety and supportability analyses; ranking failure according to severity classification; estimating system critical failure rates; and identifying reliability and safety critical components. (Reliability Analysis Center, 1993).

b. FRACAS

FRACAS is a closed-loop process for storing, organizing, and analyzing data; tracking failures and design modifications; and reporting results throughout an organization. The kinds of data stored in a FRACAS include: failure reports, failure analysis, failure modes, design modifications, management decisions, configuration control, and lessons learned. (presentation slides from Reliability Short Course, July 2010)

c. HALT/HASS

HALT methodology use stresses beyond what system would normally see in field use to compress test time required to expose weaknesses (flaws). It is most effective in the design stage. HASS methodology uses stresses beyond what system would normally see in field use to compress test time required to expose manufacturing flaws. It is used during the manufacturing/production stage. HALT/HASS are generally developed and used for electronics and electronic systems. The following are examples of what could be varied during these tests: temperature, rate of change of temperature, vibration, voltage, power cycling, and humidity. HALT/HASS could be used on the APS electronic systems such as the radar components. (presentation slides from Reliability Short Course, July 2010)

d. PoF

PoF examines the precise nature of why and how things fail; explores the chemistry and physics of how materials are affected by the processes of manufacturing, employment, and environment; and are usually specific to a given failure mechanism. (presentation slides from Reliability Short Course, July 2010) PoF models account for things, such as potential stresses, material properties, geometry, and environmental conditions of an item. Mechanical PoF can provide a number of benefits to the reliability of equipment at all stages of the acquisition process. It can assist in assessing reliability during source selection; early identification of weak points in design; root cause of failure during testing; improvement in accuracy of accelerated life tests; update of reliability during usage; and assessment of upgrades and field kits. For an APS, PoF could be performed on the mounting brackets in order to determine if the fabricated hardware is strong enough to withstand the rough terrain of the operational environment.

2. Maintainability Improvements

Two ways to improve the maintainability of a system are by identifying all limited-life components and developing a cost effective replacement policy to maintain adequate reliability in its lifecycle; and by using "pit-stop" engineering to design the system to be easy to repair and replace.

a. Preventative Maintenance

By knowing the life of a component, a preventative maintenance schedule can be established. For example, if it is known that a motor will stop working after one thousand hours of use, the preventative maintenance schedule could include a motor overhaul (or replacement) at 950 hours of operation preventing the system from failing during operation.

b. Pit-Stop Engineering

Pit-stop engineering/design was embedded in the now canceled Future Combat System. According to Myles (2007, slide 8), "Pit-Stop design is an approach for designing maintainability in military systems that is derived from auto racing. Emphasis is on the simplicity of design to minimize downtime due to repair." Some of the characteristics of this design approach include designing the component packaging to minimize weight and volume; using modular design to allow for commonality, upgrades, and quick repair/replacement; reducing the number of tools required; including handles and grips on components; and making the design simple so that it is easy to train and maintain.

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VI. CONCLUSION

A. CONCLUSION

An APS is essential in protecting a service member's equipment and more importantly, surviving a penetration. It is important that the system is reliable, maintainable, available, and survivable. Currently, the effects of RAM are not considered when assessing the survivability of acquisition systems.

When RAM is included in the Survivability Onion, both survivability and RAM evaluations benefit, survivability assessments become more complete, RAM assessments are completed sooner, and ultimately better systems are put into the hands of our service members.

The service member has to be able to depend on his/her piece of equipment to function properly. They must be able to trust that their equipment will be ready for use at a moment's notice. If a system is not reliable and maintainable, it will not be available for use. If the system is not available, it cannot be used to protect the Service Member.

B. RECOMMENDATIONS

As APS requirements are developed, it is important that they include the Materiel Availability KPP with associated Reliability and Ownership Cost KSAs. Reliability needs to be designed into the system at the beginning of development to ensure a robust system. Maintenance metrics also need to be considered in order to minimize the logistics footprint. Pit stop engineering should be utilized, by making the system easy to repair, resulting in less downtime, increased availability, and higher survivability. By determining the most effective schedule for preventative maintenance, the unit will be able to stop failures before they occur. This will ensure that the system is in full working condition prior to leaving on a mission with confidence that their APS will stop incoming threats.

It is recommended that early testing occurs on sensitive components of an APS. This can include HALT/HASS as well as PoF activities. It is important to make sure that all electronic components will function properly and all mounting brackets hold after being shaken and jostled while driving through rough terrain.

When evaluating an APS (or any system) the independent evaluator team members need to integrate and discuss the impacts of the capabilities and limitations they observed with each other to ensure that the deficiencies are properly addressed in the reports. For example, if the RAM evaluator notices that the maintenance times are high, the survivability evaluator needs to determine how this will impact the ability of the system to protect the Service Member.

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