The Single Integrated Air Picture: Building Synergy For Theater Air And Missile Defense?

CSC 2000

Subject Area – National Security

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EXECUTIVE SUMMARY

Title: THE SINGLE INTEGRATED AIR PICTURE: Building Synergy for Theater Air and Missile Defense?

Author: Major Rey Q. Masinsin, U.S. Marine Corps

Thesis: The Single Integrated Air Picture (SIAP) coalesces various Theater Air and Missile Defense (TAMD) combatants into a single theater-wide entity that more efficiently and effectively defeat increasingly technologically sophisticated air and missile threats to the joint force. The SIAP produces synergy among TAMD combatants by forcing interactions that create a capability that is greater than the sum of the individual effects.

Discussion: Information transfer and data exchange among TAMD combatants are less than perfect. A theater of operations is typically characterized by numerous, incompatible command and control systems serving multiple agencies at varying levels of quality. Target air tracks are maintained in different coordinate frames and synchronized to varying time standards. Moreover, differing levels of connectivity and stovepiped tactical data link architectures result in an ambiguous tactical air picture within the theater of operation. This ambiguous information flow disrupts the harmonious interaction of various TAMD combatants resulting in poor prosecution of targets within joint force's integrated air defense system.

Synchronizing TAMD combatants into a single war-fighting entity requires a system that will complement disparate systems by sharing sensor, decision, and engagement data among combatant units without compromising the timeliness, volume, and accuracy of the data. The system must create an identical air picture at each combatant node. The air picture must be of sufficient fidelity to be treated as fire control quality for engagements even though another combatant 30 to 40 nautical miles away may have generated the data. If such a common, detailed database is available to provide a shared air picture, as well as the ability to engage targets that are not seen by a local combatant, then a new level of warfighting capability may be attained.

The Single Integrated Air Picture provides this capability for a network of dispersed TAMD combatants. The SIAP, however, is not in itself an end; it is only the means to achieve an end. The SIAP is merely the vehicle that a commander may use to synergize the effects of TAMD combatants to achieve theater air superiority.

Conclusion: The SIAP generates warfighting benefits to the joint force through the synergistic integration of distributed resources among its TAMD combatants. Specifically, the SIAP dramatically enhances the entire joint force's ability to detect, track, and engage technologically sophisticated targets by providing a coherent tactical air picture that is available to all the combatants all the time. Warfighting benefits flowing from the SIAP include the extension of the entire force's battlespace to and beyond the horizon limits of individual sensors, better coordination of engagements and management of scarce battle resources, and greater situational awareness over larger areas.

Section 1

Introduction

Our most vexing future advesary may be one who can use technology to make rapid improvements in its military capabilities that provide asymmetrical counters to U.S. military strengths...

The application of these technologies against us may also prove surprising. Our adversaries will have an independent will, some knowledge of our capabilities, and the desire to avoid our strengths and exploit vulnerabilities. We anticipate the probability of facing technological or operational surprise will increase in the period ahead.[1]

--Joint Vision 2010

Problem, Background, and Scope

Military operations in the twenty-first century will be conducted in an information rich environment. Detailed information about the theater of operations, for both friendly and hostile forces, represents the largest force multiplier available to operational commanders in future conflicts. As such, the Joint Task Force's (JTF) ability to gain and maintain ***information superiority***, the "capability to collect, process, and disseminate an uninterrupted flow of information,"[2] is an emerging core competency.

In today's environment, one can expect the JTF to operate in new and different ways. Lower echelons will control more lethal weapon systems over increasingly larger areas.[3] Additionally, component combatants within the JTF will plan in parallel, not sequentially, and "will make decisions in real time instead of relying on prearranged fighting instructions."[4] Joint Force Commanders (JFC) will increasingly decentralize command and control to achieve "massed effects without relying exclusively on massed forces to do so."[5]

To fight effectively in this new environment, the JTF must detect the threat earlier and defeat it at the maximum range of its available weapon systems. It needs to distinguish hostiles from friends and neutrals quickly, accurately, and unambiguously. The ability to detect, prioritize, assign, and assess information faster works to the JFC's advantage by enabling him to make better decisions more rapidly. Improved situational awareness enables the JTF to dominate the battlespace and increasingly decrease its response times to levels that the enemy cannot match. Moreover, the battlespace becomes contiguous and seamless as the JTF increases access to information and gains the ability to accurately transfer data to its component combatants with minimum delay.

The Joint Theater Air and Missile Defense Organization (JTAMDO) is the Joint Chiefs of Staff's executive agent for theater air and missile defense matters. As such, the organization's charter is to "represent the Services and Warfighting Combatant Command requirements and act as their proponent for Theater Air and Missile Defense."[6] JTAMDO's vision for TAMD explores the potential of new concepts and technologies to shape future air and missile defense operations. It is intended to "guide the development of requirements, operational concepts, and integrated architectures, as well as help structure an analysis and experiment-based assessment process."[7]

Consistent with the JTAMD vision, today's TAMD systems are migrating towards architectures that "provide tracking, combat identification, and targeting data to support long-range engagements in order to take advantage of a weapon systems' maximum ranges."[8] However, extending TAMD weapon systems to maximum ranges requires

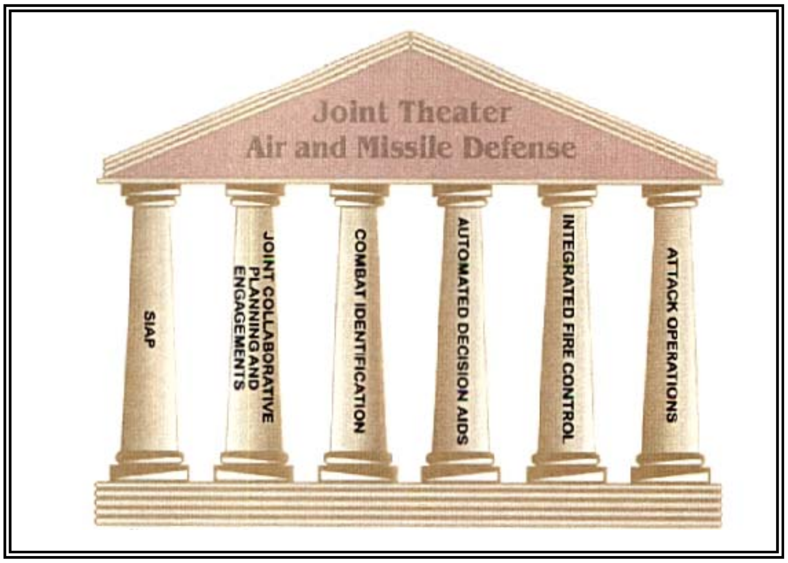

Figure 1-1 JTAMD Pillars

improved battlespace awareness which, in turn, requires quantum improvements in track detection, tracking, and identification of targets within the battlespace. To enable concepts that improve the efficiency and effectiveness of TAMD combatants and extend battlespace to create defense in depth, the JTAMD vision focuses on six key enabling concepts shown in Figure 1-1.

Theater Air and Missile Defense (TAMD) continues to be one of the most challenging mission areas for the JTF. Today's TAMD systems are stressed beyond existing capabilities as potential adversaries introduce increasingly sophisticated threats.[9] Countering these threats requires the ability to share extremely accurate information in real-time[10] between all TAMD combatants[11] thus accomplishing mutual support and defense in depth. However, today's information transfer and data exchange are inadequate to generate a coherent air picture to accomplish this task. A theater of operations is typically characterized by numerous, incompatible communication systems serving TAMD combatants at varying levels of quality. Specifically, air tracks are maintained in different coordinate grids and synchronized to varying time standards. Also, the timeline for information flow from sensors to shooters is measured in minutes or seconds instead of the required sub-seconds needed to ensure the fidelity, accuracy, and concurrency of the air picture among TAMD combatants.

Different levels of connectivity and interoperability problems among tactical information systems result in an incoherent air picture. The erratic and inconsistent flow of track data prevents the execution of the "kill chain," the required sequential steps to destroy a target, and disrupts the ability to effectively and efficiently engage and destroy the threat. Figure 1-2 depicts the kill chain and shows the sequential steps a TAMD combatant executes to engage and destroy threats within the joint integrated air defense system (J-IADS). Interoperability shortfalls among JTAMD systems are reflected in today's air picture deficiencies; such deficiencies include "lack of track continuity, lack of track clarity, and lack of track accuracy resulting in an ambiguous air picture."[12]

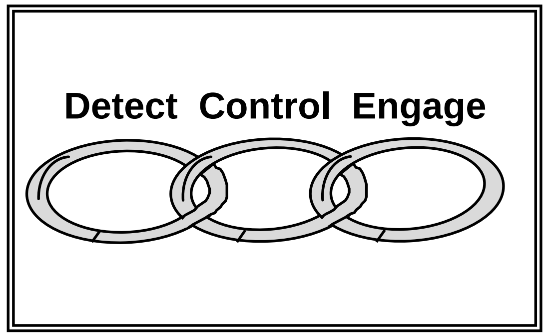

Figure 1-2 TAMD Kill Chain

While upgrades to basic surveillance, fire control, and weapon systems are required to handle sophisticated threats, improvements in ***interoperability*** and ***coordination*** among TAMD combatants are paramount in achieving synergy among TAMD combatants within the J-IADS. The JTF cannot fight effectively and efficiently if the information available to its combatants is ambiguous or worse, contradictory. The key enabling element of the JTAMD vision that will ***link*** theater air and missile defense systems is the Single Integrated Air Picture (SIAP). The "SIAP is the product of fused near-real-time[13] and real-time data from multiple sensors to allow development of common, continuous, and unambiguous tracks of all airborne objects in the surveillance area."[14]

This paper discusses the SIAP and illustrates ways in which it coalesces various TAMD combatants into a single theater-wide entity that will more efficiently and effectively defeat sophisticated air and missile threats to the joint force. The discussion will first examine the current TAMD operational environment and emerging threat systems to lay the foundation for the need for a consistent and accurate air picture. Next is a discussion on the shortfalls and inadequacies of current TAMD systems data exchange mechanisms in formulating a coherent, recognized air picture. Emphasis is given in analyzing the shortfalls of legacy Tactical Digital Information Links (TADIL) and Combat Identification (CID) systems in generating the SIAP. The main segment of this paper focuses on analyzing the operational definition of SIAP–what it is and is not. Additionally, the paper also discusses postulated benefits of achieving the SIAP, characteristics of the data elements required to generate the SIAP, and construction of the SIAP. The paper will conclude by illustrating how the SIAP produces synergy among TAMD combatants by forcing interactions that create a capability that is greater than the sum of the individual effects.

Section 2

The Littoral Environment and the Emerging Threats

The littoral region is frequently characterized by confined and congested water and air space occupied by friends, adversaries, and neutrals making identification profoundly difficult. The environment poses varying technical and tactical challenges...[15]

-- ...From the Sea

The U.S. Military must have weapon systems and equipment needed to conduct multiple, concurrent contingency operations worldwide. And it must be able to do so in any environment—including the most likely one—in which an adversary does not try to match us plane for plane, ship for ship, tank for tank, but uses asymmetric means such as nuclear, biological, or chemical weapons; information warfare; and large numbers of low cost cruise and ballistic missiles .[16]

-- Hon. Jacques S. Gansler
Undersecretary of Defense for
Acquistion and Technology

The Character of the Littoral Battlespace

Although only representing a fraction of the earth's surface area, the littorals provide "homes to over three-quarters of the world's population, locations for over 80 percent of the world's capital cities, and nearly all of the marketplaces for international trade."[17] As such, the littoral region of the world is characterized by "great cities, well populated coasts, and the intersection of trade routes where land and sea meet."[18] Insofar as the littoral region provides hopes and promises for wealth and prosperity, it also serves as a flashpoint for conflict as more and more people compete for finite resources and dispute political borders. Such instability and insecurity indicate, with a high degree of likelihood, that the conflicts of tomorrow will occur within in the littoral region.

Aside from political and economic volatility, the littorals also pose a myriad of technical challenges for TAMD. The littorals present a complex and vexing physical environment for TAMD; an environment characterized by high density air and maritime traffic, abundance of sensor clutter due to geography, and a high incidence of "anomalous tropospheric refraction of electromagnetic waves."[19] What follows is a discussion of the negative effects of the three phenomena mentioned above as they pertain to TAMD. These factors, separate or combined, contribute greatly to the degradation of the JTF's ability to conduct air and missile defense operations. Figure 2-1 shows the complexity of a typical air and missile defense environment in the littorals.

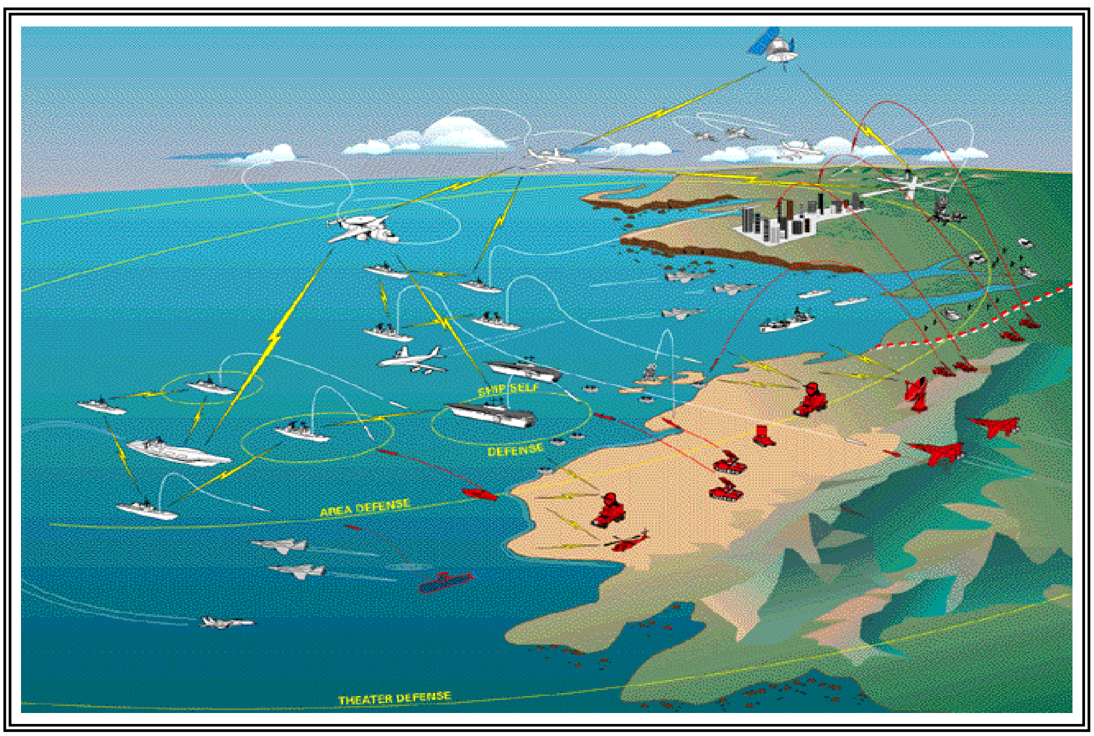

Figure 2-1 Littoral Air Defense Environment

Since 80 percent of the world's capitals are located in the littorals, these regions contain the highest density of air traffic in the world. Typically, 90 percent of all air traffic in a given region perfom commerce; the remainder is military traffic.[20] Such a large volume of air traffic significantly stresses TAMD sensor networks and communications performance. Large target loading saturates system processors and increases computational complexity. For example, the AN/TYQ-23 Tactical Air Operations Module (TAOM), the Marine Corps' air defense operations center, has a capacity for 250 tracks.[21] Additional tracks reported to the TAOM once track storage saturation is attained are discarded and not displayed to the operator. Results from various exercises, such as Fleet Battle Experiment Charlie conducted in the Virginia Capes (VACAPES) Operation Area, show track density in excess of the TAOM's capacity during periods of high air activity from Norfolk International Airport and the Navy's Oceana Naval Air Station.[22]

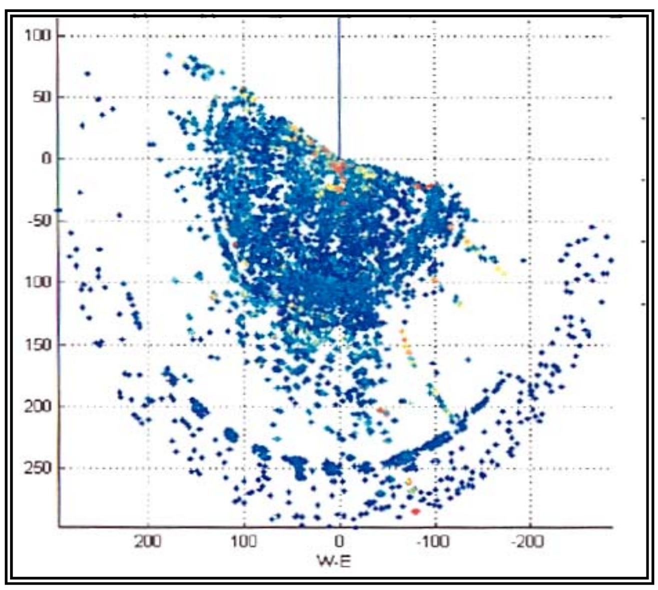

Figure 2-2 Land-sea interface clutter as depicted by a radar. The heavy clutter region is the land mass

The presence of terrain features near the land-sea interface exacerbates sensor processor saturation. The maritime component of the J-IADS employs sensors and weapon systems optimized for the low clutter, open-ocean environment. As maritime combatants are forced to approach closer to land masses, sensors are overwhelmed with clutter returns from land masses and built up areas. As a result, clutter returns impede a maritime combatant's ability to discern low radar cross section targets flying from landward to seaward and thus pose a severe threat. Figure 2-2 depicts a clutter region in the land-sea interface.

Land based sensors are not immune to the effects of geography. Although optimized for tracking targets overland,[23] the effects of terrain also exert a negative effect on sensors. Terrain masking of hostile targets prevents detection since electromagnetic energy cannot penetrate such obstacles. Line of sight determines a sensor system's surveillance area; gaps in the surveillance area caused by terrain blockages make ideal avenues of approach for enemy aircraft.

Perhaps the most problemmatic physical phenomenon, and occuring with high incidence in the littorals, is the presence of anomalous tropospheric refraction of electromagnetic waves, or simply anomalous propagation (AP). Two variations of AP present a challenge to TAMD: Ducting[24] and clear air turbules (CAT).[25] The performance of radar and communication systems is "greatly affected by the refractive properties of the troposphere. Under extreme conditions, principally dependent on the rate of change of humidity with altitude, anomolous propagation occurs and seriously limits performance."[26]

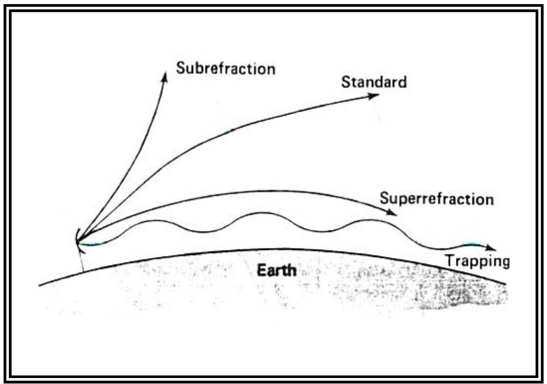

Figure 2-3 Effect of trapping electromagnetic wave in a duct

Ducting occurs when "the rapidly varying refractivity of the atmosphere produces extreme bending of the electromagnetic wave which can take the form of energy being trapped in a duct. This condition usually causes long range transmission of the energy which confuses and degrades the performance of the radar.[27] Figure 2-3 shows the effect of trapping electromagnetic energy in a duct. Moreover, trapping electromagnetic waves in a duct creates a "blind area" above the ducting layer. Targets flying between refracted layers remain undetected by the sensor. A cruise missile flying above a ducted layer, as shown in Figure 2-4, will remain undetected until it traverses below the duct; this condition compresses a combatant's reaction time to deploy countermeasures or activate self-defense weapon systems.

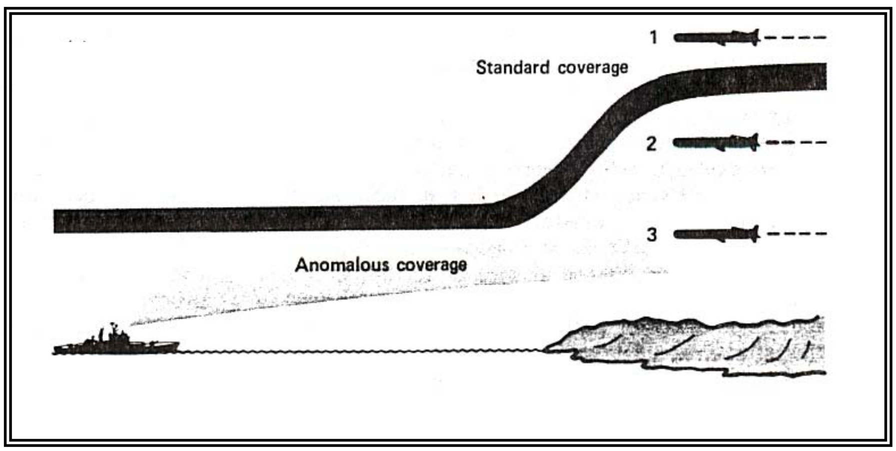

Figure 2-4 Potential radar coverage problems from elevated anomalous refracted layer. In this case, the TAMD combatant fails to detect objects above the trapping layer (solid line).

CAT is an atmospheric phenomenon that "exhibits low velocity, trackable point target behavior which is hard to distinguish from real targets."[28] The coherent movement of turbules "creates" clutter that appears to move at approximately 60 knots and presents a radar "return" similar to a typical 0.1 to a 1 m^2 air target . As mentioned earlier, clutter overwhelms the sensor's processor. More important, however, is the fact that radar expend scarce energy resources to resolve false targets instead of searching for valid targets threatening the JTF. Figure 2-5 shows clutter created by CAT at approximately fifteen to twenty thousand feet. This altitude block corresponds to the weapons release point for many tactical air-to-surface missiles that may be employed against the JTF.

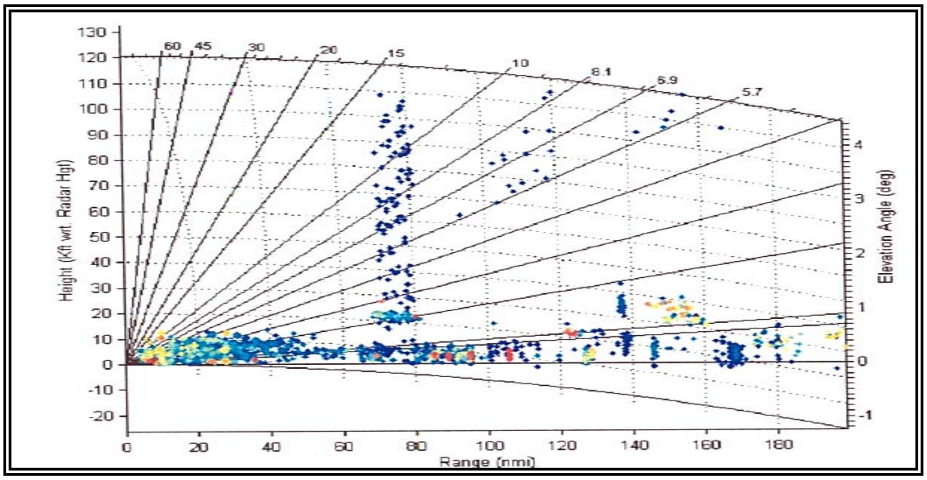

Figure 2-5 Clear air turbulence shows up as a band of clutter between 25-30K feet MSL

As discussed in the previous section, air and missile defense operations in the littorals are challenged by politics, geography and atmospherics. The confluence of heterogeneous sensors operating under different procedures presents interoperability problems. The presence of environmental anomalies marginalizes the performance of already stressed TAMD systems. The environmental factor, however, is only one variable in the TAMD equation. The following section discusses the contribution of the emergence of sophisticated targets to the complexity of the TAMD problem.

Asymmetrical Threats: Ballistic and Aerodynamic Missiles

Similar to the environment, the evolving threat to TAMD will take on new, stressing characteristics in the 21st Century. *Joint Vision 2010* states that the "most vexing future adversary may be one who can use technology to make rapid improvements in its military capabilities that provide asymmetrical counters to U.S. military strengths."

Asymmetrical counters, however, do not preclude the incorporation of effective yet inexpensive technology. Ballistic and aerodynamic missiles, collectively called theater missiles, of formidable capability may be inexpensibly produced in large numbers. Figure 2-6 illustrates the cost advantage of acquiring theater missiles *vis a vis* conventional weapons. A robust force of ballistic and aerodynamic missiles can significantly contribute to an "otherwise low-technology asymmetical force to dislodge regional enemies, prevent their reinforcement by high-technology allies, or otherwise buy time to create a more favorable political solution."[29]

There are two primary reasons for the proliferation of theater missiles within third world countries, rogue nations, and failing states. First, the trend towards theater missiles is driven by cost and a strategy to counter, instead of match, enemy capabilities. As Figure 2-6 shows, potential adversaries can obtain a significant number of ballistic and cruise missiles for the price of one or two technically sophisticated manned aircraft. Factor in the added cost of training, maintaining, basing, and sustaining a manned aircraft fleet and one easily comes to the conclusion that theater missiles can provide high operational impact for nominal costs. The second factor contributing to the proliferation of theater missiles is the availability of technology for "third world nations to upgrade short-range missiles to produce new land-attack cruise missiles."[30] Commercial GPS

Figure 2-6 Given equal funding, an adversary could buy up to 40 low cost off-the-shelf cruise missile or 1-2 fixed-wing fighter aircraft

navigation instruments, compact avionics, flight programming software, and powerful, light weight jet propulsion systems are a few examples of technology readily available in today's open market.

Tactical Ballistic Missiles (TBM) and cruise missiles are two of the most problemmantic threats to the integrated air defense system. TBMs are often launched from mobile, difficult to detect transporter erector launchers (TEL) and have the inherent capability to carry weapons of mass destruction. Most TBMs are "single-stage missiles with circular error of probable accuracy of one-tenth of one percent of its range. State of the art guidance technologies in some missiles will reduce these accuracies to less that 50 meters."[31] TBMs are inherently difficult to engage due to several characteristics; these characteristics include high velocity, low radar cross sections (RCS), and multiple warheads.

Emerging cruise missiles pose serious threats because of the incorporation of new technologies in airframe and warhead design, propulsion systems, and guidance systems. Low observable and stealth technologies have significantly lowered the RCS of a newer generation of cruise missiles. Additionally, the increased use of "air breathing turbojet and turbofan engines permit subsonic speeds, providing longer ranges and flight altitudes as low as 20 meters above ground level."[32] The availability and incorporation of commercial positioning technology, such as GPS or inertial navigation systems (INS), into cruise missile frames have allowed increased accuracies and allow programming of unpredictable flight paths to optimize shock to the intended target.

Although not as widespread as ballistic and cruise missiles, another threat is emerging and warrants a brief discussion. Unmanned Aerial Vehicles, or UAV, possess the same attributes as cruise missiles. Significant is the very low RCS feature of this air vehicle that makes it almost undetectable with radar. Low RCS and flight profiles which take full advantage of terrain make UAVs an ideal platform to penetrate heavily defended IADS with low probability of detection. The UAV is yet another way for a rogue state to gain an asymmetric advantage over a technologically superior enemy; the ability to observe, locate, and target enemy forces without access to high technology, high cost, high maintenance, space-based observation assets is one such example.

The emergence of a new generation of sophisticated, difficult to detect threats, coupled with the increasing trend to operate in the challenging littoral environment, raises the urgency for the United States to develop TAMD systems and corresponding techniques, tactics, and procedures (TTP) to counter such threats. Current TAMD systems cannot cope in such an environment. The next section explores the shortfalls of current TAMD systems in countering the threat presented in the discussion above.

Section 3

Shortfalls of Current TAMD Systems

Recent exercises, evaluations, and operations continue to reveal recurring tactical C^2 systems interoperability shortfalls which negatively impacted the ability to build and maintain a Common Tactical Picture and provide needed Combat ID to our warfighters.[33]

-- Chairman, Joint Requirements
Oversight Council

Linear Versus Integrated Destruction Zones

As late as the mid-1980s, theater air defense doctrine advocated the employment of linear destruction zones.[34] Airborne fighter aircraft push as far forward as possible in the JTF's battlespace to provide the first layer of defense against incoming air threats. Directly behind the fighters' engagement zones (FEZ) are missile engagement zones (MEZ), areas set aside in the battlespace where the primary responsibility for engagement normally rests with surface-based air defense systems[35]. This linear array of destruction zones provides destruction in depth and simplifies the problem of combat idenfication. Hostile aircraft attacking the JTF are first subjected to potential destruction by fighter aircraft within the FEZ; surviving threat aircraft are re-engaged by surface-based missile systems as they penetrate the MEZ. Leakers[36] are subject to a heavy density of anti-aircraft artillery or close-in weapon systems for self-defense. Moreover, the linear structure of an air defense destruction zone facilitates target identification within the TAMD battlespace. For example, aircraft in the destruction zone not adhering to prescribed return-to-force procedures, such as following a designated air corridor at the correct altitude and speed, are declared hostile and engaged. Figure 3-1 shows an example of a linearly arranged destruction zone.

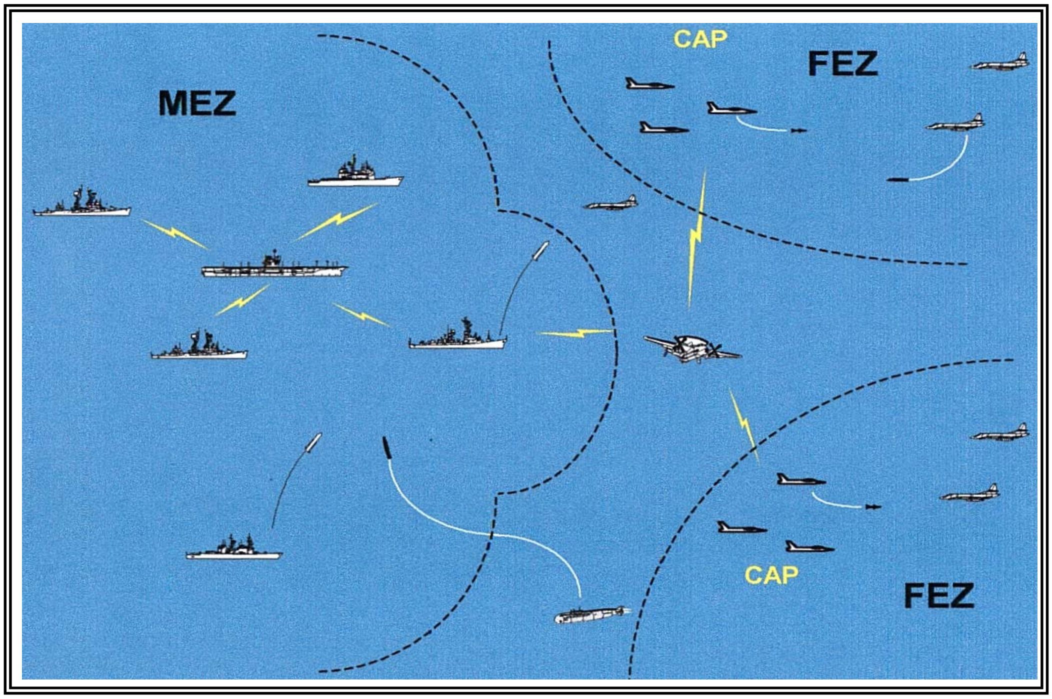

Figure 3-1 Linear Destruction

Despite its simplicity, linear destruction zones sub-optimize TAMD system effectiveness for two reasons. First, the sequential arrangement of FEZ and MEZ negates mutual support from ***both*** fighters and ground-based air defense assets. Fighter aircraft are not allowed to pursue threat aircraft outside the FEZ; conversely, missile systems do not engage targets until they have entered the MEZ. Thus, linear defenses subject the threat aircraft to only one type of weapon system at any given time and increases its potential to employ countermeasures. Second, the transition between the FEZ and the MEZ constitutes a "friction point" between TAMD elements. The seams between the engagement zones require a high degree of coordination to ensure the proper hand-off of target aircraft from one weapon system to another.

A linear destruction zone is ideal in the large, low-density, homogenous enviroment that characterize air defense operations in the past. Today's military emphasis on the littoral regions, however, requires new concepts that adapt to the challenges of this unique environment. The compressed nature of the littoral battlespace precludes partitioning the airspace into compartmented engagement zones. Instead, an integrated, seamless *joint engagement zone* (JEZ), where fighter aircraft and ground-based air defense systems operate ***simultaneously***, is the preferred and optimal way to conduct air defense operations in the littoral environment.

The key enabler to the JEZ concept is a clear, consistent, and accurate air picture shared by all TAMD combatants in the theater of operation. However, current TAMD combatants' communications systems currently "lack the capability to provide, in near-real-time, the quantity and quality of accurate information needed by each element to perform its mission." [37] What follows is a discussion of the root causes of the three most vexing problems in executing an integrated air defense system: sensor inaccuracy, inconsistent tactical air picture, and poor combat identification.

The Air Defense Functional Model

A good starting point for the discussion of the shortfalls of the current TAMD system is a basic understanding of the air defense functional model.[38] Figure 3-2 depicts the elements of the model and identifies the heirachy of tasks required to successfully destroy an air target. The TAMD "kill chain," introduced in Section 1, spans the tasks outlined in the model; it is subdivided into hierarchial tasks that define the sequential flow of data from sensors to shooters. Interruption of data flow within the model translates to an aborted engagement that requires the reinitialization of the process. Disrupted "kill chains" compress a combatant's battlespace and minimize reaction time to initiate defensive actions against a threat.

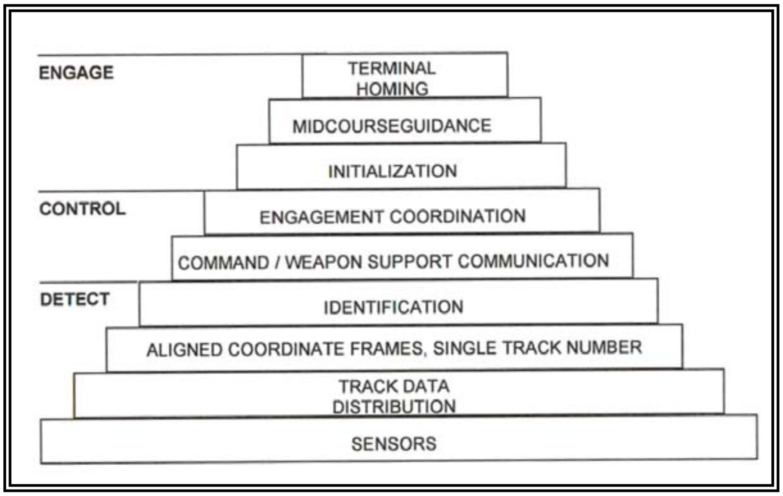

Figure 3-2 The Air Defense Functional Model

The preponderance of TAMD deficiencies today are rooted within the "detect" domain of the model. Data from numerous operational exercises pinpoint problems with track continuity, track data transfer, and track identification as the predominant source of interoperability problems in the J-IADS today. As such, the analysis below focuses on these three problem areas.

Root Cause, Part I: Sensor Limitations

To successfully perfom its intended mission, TAMD combatants within the JTF must defend themselves and vital assets with weapon systems dispersed over thousands of square miles. Each combatant possesses one or several sensors, and each sensor will "observe a somewhat different view of the situation because of its unique characteristics and vantage point."[39] Such diversity in sensor capabilities and vantage points results in different views of the battlespace among the combatants. Figure 3-3 illustrates this point.

Radars depend on reflected electromagnetic energy to detect a target. However, anomalies in the environment, such as ducting and anomalous propagation, and deliberate enemy actions, such as jamming and terrain masking, prevent radars from detecting a target continuously as it traverses the surveillance area. Consequently, "fade zones" emerge when radar tracking is momentarily inhibited and the track "lost." If the radar fade area is large enough, the tracking system "drops" the track along with all its associated attributes, such as identification, altitude, and raid size, from its database.[40] This event abruptly distrupts the "kill chain" and stops an engagement process. Even if a target emerges from a fade zone a few seconds later, the system has to reinitialize the track, wait several seconds to establish a firm track, and re-identify the target to engage it. In such a scenario, a supersonic threat aircraft may reach its intended ordnance release point well before a combatant regains the track and situational awareness to engage the target.

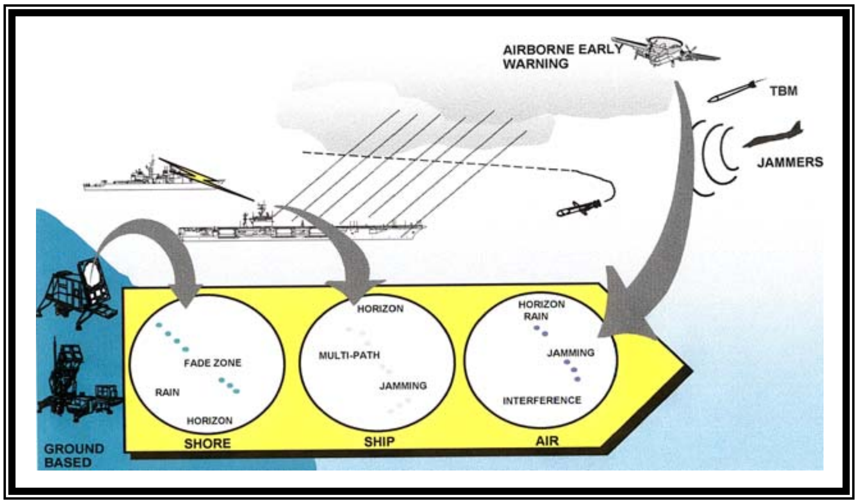

Figure 3-3 Sensor Limitations due to natural phenomena and deliberate enemy actions

Root Cause, Part II: The TADIL Babble

The primary method for integrating disparate TAMD combatants today is through Tactical Digital Information Links, or TADIL. TADILs provide the primary linkage between TAMD systems by allowing geographically separated units to share an air picture and digitally pass orders and information. TADILs transfer information between participants in near-real-time; protocols for data exchange are governed by JCS standards that are agreed upon by all the Services.

The TADIL Elephant

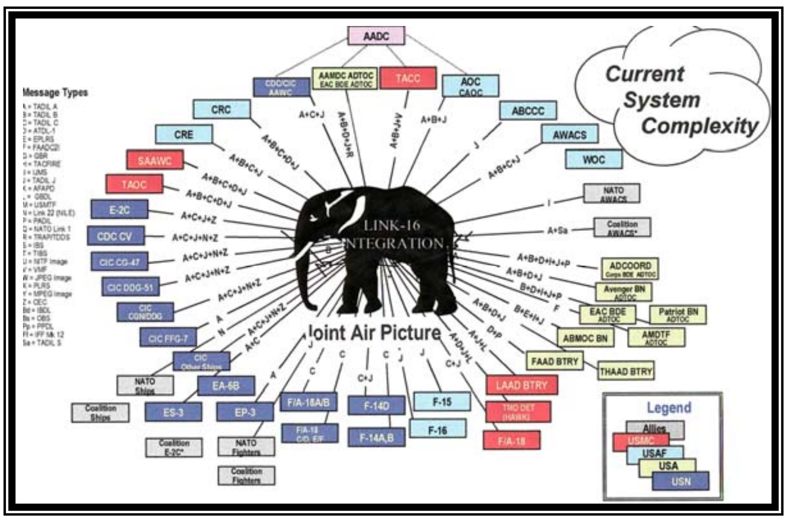

Figure 3-4 Current Joint Air Picture

There are over fifteen data link protocols used by U.S. Services and allied nations within the J-IADS today. While some data links adhere to approved standards,[41] others are single service, proprietary data links unique to a particular weapon system.[42] A problem results when these disparate systems are assembled together to form the J-IADS data network. Figure 3-4 depicts the diversity and complexity of data transfer methods existing in the J-IADS today.

Recognizing the problems associated with the proliferation of unregulated data link protocols, the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I)) "amplified DODD 4630.5, C4I interoperability policy, and designated Link 16 as DOD's primary data link."[43] To this end, the ASD(C3I) chartered a Tactical Data Link Working Group, composed of the Joint Staff, Services, and various other governmental agencies, to develop a Joint Tactical Data Link Management Plan (JTDMP). Specifically, the JTDMP's goals include:

- Establish the J-series Family of Tactical Data Links (TDLs)
- Improve interoperability by using standard messages and DoD Standard Data Elements.
- Reduce interfaces between TDLs.
- Reduce proliferation/duplication of data links
- Improve information dissemination
- Reduce data loss due to message and data elements translation differences between TDLs
- Exchange J-Series Family messages independent of specific communications media
- Allow the introduction of emerging technology into the joint operating environment [44]

Despite OSD level guidance, however, Services continue to use data links that do not belong to the J-Series Family of Data Links.[45] As a result, disparate message formats and communications media have significantly reduced interoperability among diverse TAMD combatants in the J-IADS. The forwarding of incompatible data link elements from one type of data link to another has long been identified as a source of interoperability problems within the J-IADS. The impact of routing and forwarding dissimilar message sets among TAMD combatants results in "TADIL-babble;" the condition is similar to what two people speaking different languages may experience when communicating with one another.

The Tactical Air Picture Deficiencies

Severe problems exist today in coordinating and synergizing TAMD combatants with TADILs alone. The continued growth of the TADIL "elephant" exacerbates the problem and ensures a deeper spiral into non-interoperability. Unfortunately, the problem extends past non-compliance of TAMD systems to migrate to the mandated TADIL-J standard.[46] The standard itself is flawed in that the language contained in the standard is too vague and subject to different interpretation.[47] For example, ICP TJ 95-013, Update Point/Line/Area/Descriptor in the J3.0 TADIL-J message states that the "implementation of the ICP is not required...a system not implementing this change is not worse off than the current situation."[48] However, a recent operation revealed that some of the TAMD systems implemented the ICP while others did not. Systems that did not implement the ICP failed to process theater ballistic missile impact point and failed to display the information to the operator.[49]

Another problem with the standard is compliance enforcement. Although the Joint Interoperability Test Command (JITC) is charged with testing and certifying joint interface standards compliance, it lacks the power to prevent violators from fielding systems that do not conform to the standards. To this date, the majority of TAMD systems have not received JITC certification. Until the Sevices' materiel commands are directed to undego mandatory certification *and* the JITC empowered by OSD to enforce penalties for non-compliance, the Services will continue to field TAMD systems that do not fully comply with mandated standards.

The result of the growth of disparate TADILs, coupled with the existence of vague standards and lack of compliance, is an incoherent tactical picture that cannot support the JTF's TAMD requirements. The problem is serious enough that the Chairman, Joint Requirements Oversight Council noted that "recent exercises, evaluations, and operations continue to reveal recurring C^2 systems interoperability shortfalls which negatively impacts the ability to build and maintain a coherent tactical picture..."[50]

The All Services Combat Identification Evaluation Team (ASCIET) conducts a biennial evaluation of current TAMD systems to assess the effectivess of the J-IADS to pass ID information to the shooter. In ASCIET 99, the evaluation quantitatively revealed the shortfalls of the J-IADS. ASCIET 99 data empirically supported the hypothesis that the current TADIL architecture is insufficient to coordinate TAMD combatants within the JTF theater of operations.

ASCIET assessed the tactical air picture available to TAMD combatants by "measuring its commonality, completeness, clarity, and continuity."[51] Although the actual numbers in the ASCIET report is classified, this paper provides *qualitative* assessment of the evaluation's findings to provide the reader a sense of the magnitude of the TADIL shortfalls in the J-IADS. The following is the author's qualitative assessment of the J-IADS performance at the ASCIET 99 evaluation. The author uses a "stop light" chart to gauge the relative performance of the J-IADS during ASCIET 99. Table 3-1 defines the metric used for this analysis.

G	No significant degradation to mission accomplishment
Y	Minor degradation to mission accomplishment
R	Significant degradation to mission accomplishment

Table 3-1 Metrics for assessing J-IADS performance at ASCIET 99 evaluation

Commonality

Y/G	Overland J-IADS commonality
Y/R	Overwater J-IADS commonality

Table 3-2 J-IADS Commonality Performance

Commonality among TAMD combatants exists when "all systems hold the track at the same position with the same identification at the same time."[52] ASCIET data reveal a slight difference in TAMD combatants holding a common air picture over land than over water. Lack of commonality among the combatants is attributed to two primary reasons: Combat system problems and messages not received by all participating systems. Combat system problems such as "improper filtering, improper registration, improper track extrapolation, miscorrelation or misassociation, and effects of prolonged unresolved ID conflict"[53] are the primary reasons for lack of commonality.

Connectivity among TAMD combatants across a wide theater of operations is the single predominant reason for lack of air picture commonality. Dispersion, enviromental

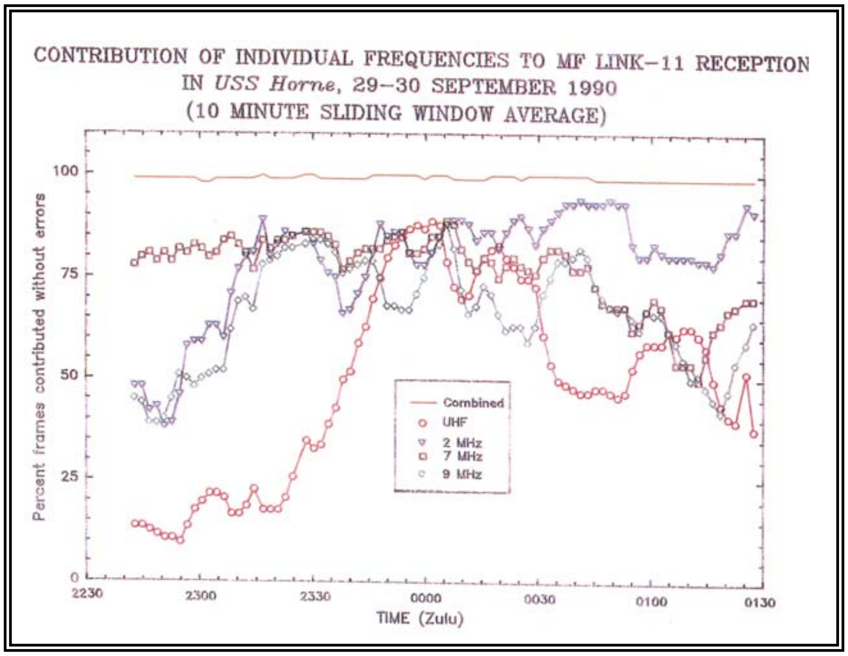

Figure 3-5 TADIL Connectivity achieved by the USS Horne. Note that at times, there is only a 15% connect rate with other JTAMD participants

anomalies, and radio frequency selection all contribute to poor connectivity among combatants. Consider Figure 3-5, above, where the USS Horne's connectivity with other TAMD combatants varied widely between different frequencies used for TADIL-A (Link-11). Most significant is the fact that the USS Horne achieved only 80% connectivity as its best case perfomance during the sampling period and less than 15% success at the worst.[54] Figure 3-6 illustrates an example of lack of commonality; in this case, track number 1057 is classified as "hostile" by one JTAMD combatant and at the same time classified as "unkown" by the AWACS. Such disparity in the J-IADS air picture detracts from the combatants' ability to realize unity of effort and mutual support.

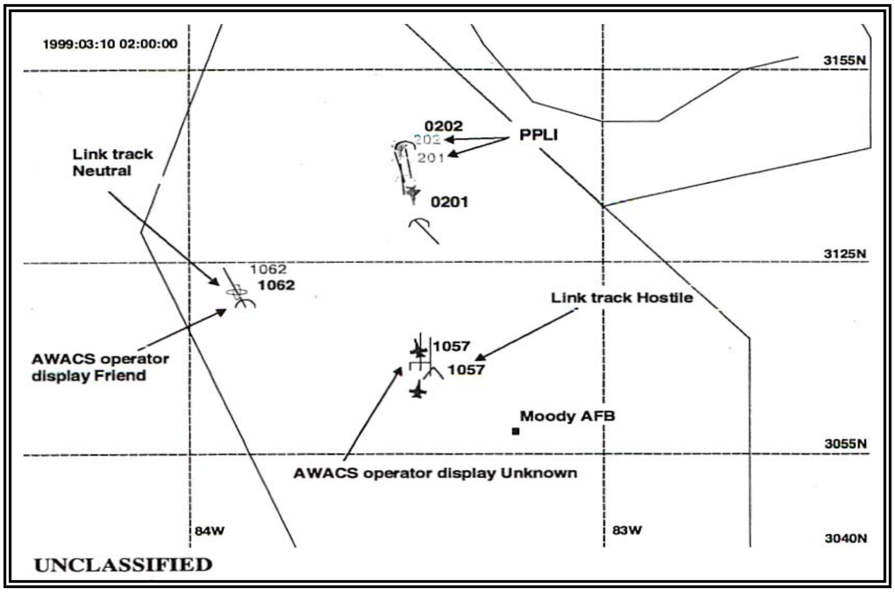

Figure 3-6 Uncommon link picture between TAMD combatants

Completeness

Y	J-IADS Completeness

Table 3-3 J-IADS Completeness Performance

An operator's display of an aircraft formation is complete if "the display held at least one track on the aircraft formation."[55] Unlike commonality, the completeness metric does not require the track to have the same attributes all the time. The problems associated with lack of commonality also contribute to the lack of air picture completeness.

Clarity

R	J-IADS Clarity

Table 3-4 J-IADS Clarity Performance

A clear picture is one that is "free from redundant (dual) tracks."[56] A dual track is a condition where more tracks (local and remote) are on a formation of aircraft than there are aircraft in that formation. During ASCIET 99, "operators and observers noted a high incidence of redundant tracks within the J-IADS."[57]

Several reasons account for the lack of clarity in the air picture. Most fundamental is the inability to properly align individual sensors to the north. Slight rotational error of a few milli-radians, while of little consequence close to a radar, translates to tens of kilometers of bias at long ranges. Two combat systems whose organic radars detect the same target may report two different tracks because of this rotational error.

Another reason for lack of clarity is a system's inability to correlate and decorrelate tracks. Combat systems are required by the TADIL standards to correlate different tracks reported that represent one target. Such action reduces ambiguity by allowing only one track per target on the operator's screen. Failure to correlate targets results in multiple tracks on one target and reduces the clarity of the air picture. Decorrelation, on the other hand requires the combat system to assign another track if two distinct targets emerge from one radar contact. For example, a two-aircraft fighter section may be detected only as a single target and assigned a single track. As the formation separates, the combat system is required to initiate a track on the new contact diverging from the original track. Different implementation of the correlation and decorrelation rules account for the disparity in combat systems' varying techniques for accomplishing this integral task. Inconsistent, or worse faulty, logic among TAMD systems' ability to execute this essential task results in an incoherent track picture.

Identification Continuity

R	J-IADS Identification Continuity

Table 3-5 J-IADS Identification Continuity Performance

Under ideal conditions, the identification (ID) on a friendly aircraft starts out as an "unknown" then upgrades to "friend." In contrast, track ID on hostile aircraft upgrades from "unknown" to "hostile." Thereafter, the track ID should persist with the track for as long as the track remained in the surveillance area. However, during ASCIET 99, TAMD combatants experienced the following:

> "one or more downgrades [of an identified track] to 'unknown', usually as a result of tracking lapses caused by hostile aircraft maneuvers or a descent below the radar's coverage. More dangerous is the tendency for 'friend' tracks to become associated with 'hostile' groups primarily as a result of track swaps and miscorrelation"[58]

ID differences between the disparate TADIL protocols also contribute to lack of ID consistency. Consider the case where one combatant compliant with TADIL-J protocol forwards the picture to another combatant that is operating on TADIL-A.

TADIL-J expands the possible taxonomy under which targets may be classified. While TADIL-A provides three possilbe ID categories, TADIL-J allows eight different categories. A "suspect" track passed by a TADIL-J combatant to a TADIL-A combatant maybe translated to a "hostile" or "unknown." A worse condition is the receipient not displaying the forwarded track since the ID attribute does not fit its taxonomy. Table 3-6 shows the disparate taxonomy between two TADILs.

TADIL-J	TADIL-A
PENDING	PENDING
UNKNOWN	UNKNOWN
ASSMD FRND	-----
FRIEND	FRIEND
NEUTRAL	-----
SUSPECT	-----
HOSTILE	HOSTILE
UNDEFINED	-----

Table 3-6 Difference in ID taxonomy between TADIL-J (link-16) and TADIL-A (Link-11)

Root Cause, Part III: The Combat ID Shortfall

While incidents of individuals and units firing on friendly forces may be documented as far back as the introduction of gunpowder, the changes in the speed and lethality of 21st century TAMD weapons have made them of great concern today. TAMD destruction areas are characterized by beyond visual range (BVR)[59] engagements in JEZs where friendly aircraft operate in proximity of hostile aircraft. The Combat Identification (CID) problem is exacerbated by the mixture of high density "white air"[60] operating within the world's air corridors and converging in the littoral regions where military operations are most likely to occur.

The CID mission area seeks to "rapidly and accurately identify friend, foe, and neutral elements on the battlefield in order to maximize combat efficiency and minimize the risk of fratricide."[61] CID in the TAMD arena is achieved by merging two distinct but interrelated domains: Situational awareness (SA) and target identification (TI). SA "is the near real-time, accurate knowledge of one's own location, the location of other friendly forces, the location of enemy forces, and the location of neutrals."[62]

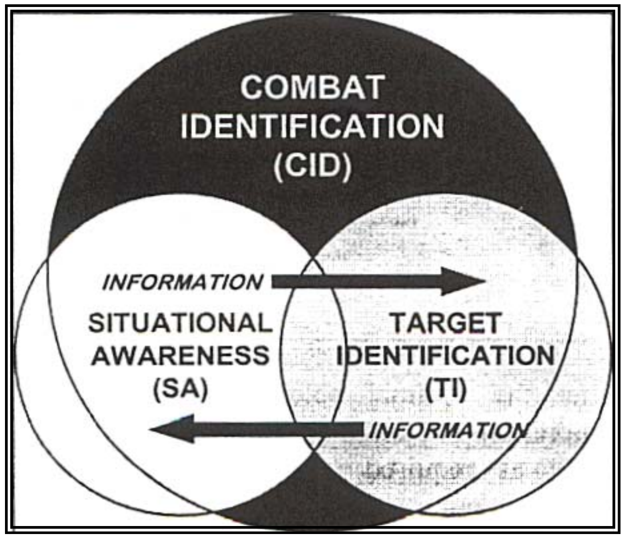

Figure 3-7 SA and TI relationship

Within the TAMD environment, SA among combatants is achieved through the exchange of information via TADILs as shown in the discussion above. TI, on the other hand, focuses on a combatant's ability to "interrogate or fingerprint a potential target to aid the operator's shoot/no-shoot decision."[63] Figure 3-8 illustrates the relationship between SA and TI.

Perhaps the biggest shortfall in CID is the lack of organic TI systems among TAMD combatants. Currently, only a handful of specialized units possess TI systems to provide non-cooperative target recognition (NCTR)[64] in a theater of operation.[65] Such units are normally theater assets, under the control of the Joint Force Air Component Commander (JFACC), and provide identification information on air contacts within an assigned sector. Another CID shortfall is the TI system's inability to directly insert CID information into the SA network. TI operators still use voice nets to communicate CID information to TAMD operators; in turn, TAMD operators manually insert the information into the TADIL network for dissemination.[66]

Once the TI information is present in the SA network, the dissemination process is hampered by the inconsistent nature of the TADILs as described earlier. Once again, a track that is "dropped" by a combat system loses all the CID attributes that accompany the track. In essence, a broken "kill chain" requires the combatant to return to the first step of the "kill chain" just as the threat closes on its intended ordnance release point. Moreover, dual tracking exacerbates the ID shortfall. Dual tracks increase an operator's workload as he attempts to resolve an ID conflict. ID conflict resolution requires manual intervention by operators; the process requires voice coordination that further erodes the combatants' ability to engage the threat aircraft at the maximum range of its weapon system.

Clearly, the problems identified in this section prevent the efficient and synergistic function of TAMD units. Shortfalls in sensors, data transfer, and CID systems all contribute to the inefficient manner in which the J-IADS operate. As newer, faster, stealthier, and more sophisticated air vehicle threats continue to proliferate, rogue nations and failing states gain a larger advantage to asymmetrically attack this critical vulnerability.

Section 4

The Single Integrated Air Picture

> *The Single Integrated Air Picture is the product of fused, near-real-time and real-time data from multiple sensors to allow development of common, continuous, and unambiguous tracks of all airborne objects in the surveillance area.*[67]
>
> -- Capstone Requirements Document
> Theater Missile Defense

In an effort to ensure that the "Full Dimensional Protection"[68] outlined in Joint Vision 2010 becomes a reality, the JTF must be able to defend its forces that are dispersed over thousands of square miles in a theater of operations. Each TAMD combatant in the JTF possesses one or several sensors, and each sensor observes a different view of the battlespace because of its unique characteristics and vantage point.[69] Despite the disparity in information, TAMD combatants must correlate target tracks and identification data via legacy TADILs and coordinate the employment of 20 to 30 ground-based air defense systems and interceptor aircraft. However, the shortfalls in TADILs already outlined in the previous section prevent the effective coordination among various TAMD combatants.

Instead, synchronizing TAMD combatants into a single warfighting entity requires a system that will complement disparate systems by sharing sensor, decision, and engagement data among combatant units without compromising the timeliness, volume, and accuracy of the data. The system must create an identical air picture at each TAMD node. The air picture must be of sufficient fidelity to be treated as fire control quality[70] for engagements although another combatant 30 to 40 miles away may have generated the data. If such a common, detailed database is available to provide a shared air picture, as well as the ability to engage targets that may not be seen locally, then a new level of warfighting capability may be attained.

This capability is precisely what the Single Integrated Air Picture (SIAP) provides for a network of geographically dispersed TAMD combatants. However, it is important to note that SIAP itself is not an end state; it is only the means to achieve an end. The SIAP is merely the vehicle that a commander may use to synergize the effects of TAMD combatants to achieve theater air superiority.[71]

Enabling Concept: Network Centric Warfare

The advent of the Network Centric Warfare (NCW) concept revolutionized TAMD. First articulated by Vice Admiral Arthur K. Cebrowski, U.S. Navy, NCW seeks to learn from the experiences of business organizations "that have successfully adapted to the changing nature of their competitive spaces in the Information Age."[72] Central to Admiral Cebrowski's findings is that without a fundamental change in the way the military conducts warfare today, it is not possible to fully leverage the power of information in the battlespace.

Specifically, Admiral Cebrowski is critical of the discontiguous, platform centric orientation of today's battlefield systems. He argues that platform centricity produces information stovepipes that inhibit the synchronization of geographically dispersed but functionally related systems. Therefore, information stovepipes are the primary targets of

NCW. Instead, Admiral Cebrowski proposes to replace the "platform, or hierachy-centric stovepipes with fully integrated information networks."[73] He envisions such networks as forming "grids" that effectively link sensor, command and control, and shooters seamlessly. By harnessing individual combatants' capabilities in accessible networks, NCW promises the ability of "widely dispersed but robustly networked sensors, command centers, and shooters to have significantly enhanced massed effects."[74] Figure 4-1 graphically illustrates the relationship between NCW's three distinct but interrelated grids: sensor grid, command and control grid, and the shooter grid.

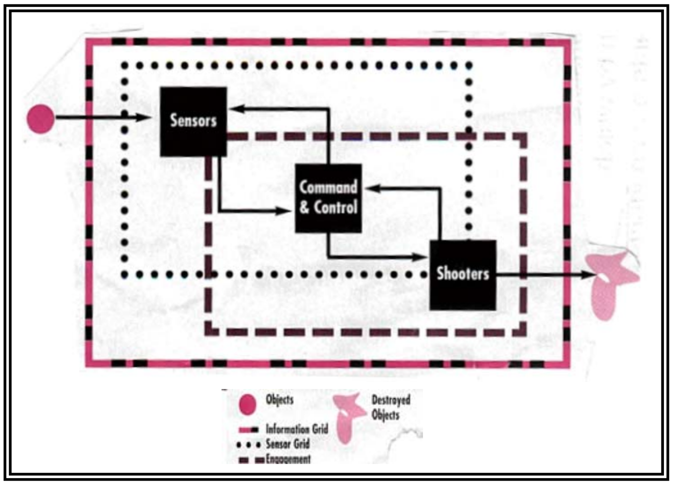

Figure 4-1 Elements of Network Centric Warfare

From Stovepipes to Networks

Realizing the collective power of networks and consistent with the construct outlined in NCW, the Joint Theater Air and Missile Defense Master Plan provides for a series of interrelated network grids to assist TAMD combatants. The three-tier system begins with a large-scale capability, narrows down to the tactical level, then focuses on the actual battlespace. First is the Joint Planning Network (JPN), "a collection of non-real-time and near-real-time communications and information systems that is used to carry out TAMD planning throughout the theater."[75] Additionally, the JPN provides a distributed collaborative planning capability, automated decision aids, and a means of distributing plans within the theater. The core of the JPN is the Global Command and Control System (GCCS).

The next tier of network is the Joint Data Network (JDN), "a collection of near real-time communications and information systems used primarily at the coordination and execution level. It provides information exchange necessary to facilitate the Joint/Service Battle Manager's comprehension of the tactical situation and provides the means to exercise command and control beyond the range of organic sensors."[76] The JDN carries battle management command, control, and communication (BMC^3) information such as unit status information, engagement status, and force orders. The backbone of the JDN is the TADIL linkages between TAMD combatants.

The third tier is comprised of the Joint Composite Tracking Network (JCTN), "a real-time joint telecommunications network and processing capability that enables composite tracking among a joint, hetergeneous mix of sensors and supports cooperative engagement of targets by weapon systems."[77] The JCTN represents the most challenging network grid to produce since it requires the transfer of shooter quality data from one shooter to another with enough fidelity for the recepient to conduct engagement. Sharing such a high fidelity and low latency air picture among widely dispersed combatants requires new, powerful

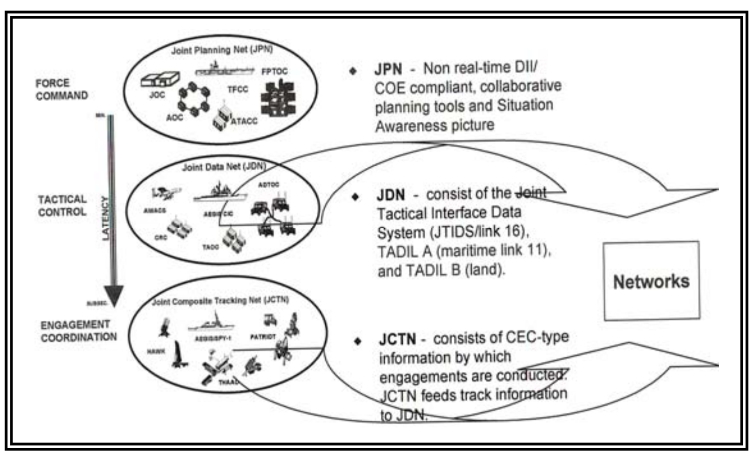

Figure 4-2 The Joint Networks

communications equipment. The Navy's Cooperative Engagement Capability system is one such system. A detailed discussion of the Cooperative Engagement Capability is presented later in this section. Figure 4-2 shows the relationship among the three tiers of networks postulated in the Joint Theater Air and Missile Defense Master Plan.

What is the SIAP?

Embedded in the Joint Theater Air and Missile Defense Master Plan's three-tier network structure of the JPN-JDN-JCTN information continuum is a corresponding level of situational awareness that emerges from each level. From the JPN domain, a Common Operational Picture (COP) is generated. The COP is comprised of "geographically oriented data, planning data from the Joint Operational Planning and Execution System [JOPES], readiness data from the Status of Resource and Training System [SORTS], intelligence (including imagery overlays), Air Tasking Order [ATO] data, and reconnaisance data from the Global Reconnaissance Information System [GRIS]."[78] Overall, the COP serves the operational and strategic level commander by providing "non perishable" planning data that is not time sensitive. It is, in essence, a complete depiction of the JFC's area of responsibility (AOR).

A subset of the COP is the Coherent Tactical Picture (CTP). The CTP encompasses both the JPN and JDN data domain and refers to "the current depiction of the battlespace for a single operation within the AOR including current, anticipated or projected, and planned disposition of hostile, neutral, and friendly forces."[79] Within the TAMD arena, the TADIL system provides the near-real-time data of the CTP and serves the operational and tactical level commanders for command and control of aircraft and missiles.

The SIAP is a subset of the CTP and encompasses both the JDN and JCTN data domains. The SIAP is defined as the product of "fused, common, continuous, unambiguous tracks of all airborne objects in the surveillance area. Each object within the SIAP has one, and only one, track number and a set of associated characteristics."[80] The SIAP is developed from near-real-time and real-time data sources; it is scaleable and filterable to support situational awareness, battle management, and target engagements by TAMD tactical commanders. Thus, the SIAP represents the air component of the CTP. The CTP, in turn, depicts in near-real-time the complete tactical picture of the battlespace (air, surface, and sub-surface) and "feeds" the operational and tactical level COP[81]. This relationship is depicted in Figure 4-3.

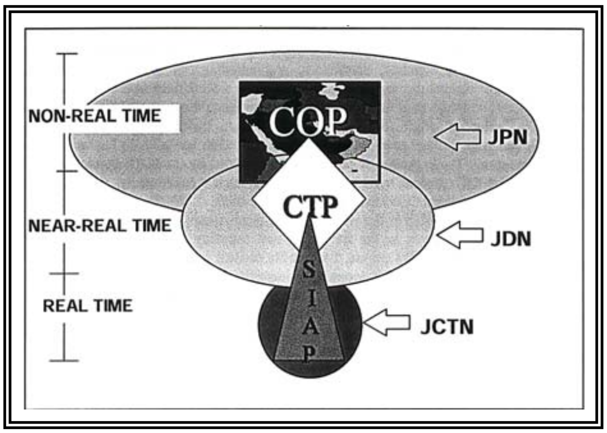

Figure 4-3 COP-CTP-SIAP Relationship

What the SIAP is not

It is important to understand what the SIAP is. It is equally important to distinguish what SIAP is not. First, as mentioned earlier in this section, the SIAP is not an endstate to itself. The SIAP does not contain all the information upon which a TAMD commander bases his decision to conduct an engagment. The commander must equally weight information not included in the SIAP, such as rules of engagement, weapons control status, and system status, before making engagement decisions. Instead, the SIAP generates an unambiguous picture from which the commander applies these rules to facilitate air engagements to gain theater air superiority. Second, it is important to recognize that the SIAP itself is not a network; instead, the SIAP is the resulting product of aggregating, at each combatant's location, specific information shared across the JDN and JCTN networks. Third, the SIAP is not a situational awareness picture created by one combatant and passed around to other combatants similar to the TADIL protocol. Instead, the SIAP is generated locally by each combatant by manipulating the data being shared across the JDN and JCTN networks. In this way, the SIAP preserves the timeliness of data by avoiding the transfer of entire databases over low-bandwidth communications paths. Finally, since the SIAP only concerns the aerospace medium, it does not contain data elements to produce a picture of the surface or subsurface tactical situation.

Engineering the SIAP

Although the concept of the SIAP is well articulated in literature, it is still some distance away from being realized by the warfighter. The problem is not technological; instead, it is rooted within the Services' materiel commands' reluctance to commit research and development funds for a warfighting requirement that is not validated by the Joint Requirements Oversight Council (JROC). However, Service reluctance is reversed when inputs from the recently formed Interoperability Joint Warfighting Capabilities Assessment (I-JWCA) team prompted the JROC to support the recommendation to "designate a lead organization that will be responsible for the systems engineering necessary to develop and field the SIAP."[82] Specifically, the JROC tasked U.S. Joint

Forces Command to recommend a lead organization for SIAP engineering to the JROC to enable final designation by January 2000.[83]

On the other hand, the Program Manager for Air Defense Systems at the Marine Corps Systems Command (MARCORSYSCOM) has long envisioned the utility of the SIAP to the TAMD mission area. To this end, MARCORSYSCOM has conducted several experiments and demonstrations towards the development of a SIAP. The methodology used by MARCORSYSCOM is described below and forms the cornerstone for one potential approach to engineering the SIAP.

Laying the Foundation: The Cooperative Engagement Capability

As discussed earlier, the biggest hurdle in achieving synergy among discontiguous TAMD combatants is the lack of a common air picture. Currently, each TAMD combatant develops its own track files (databases) and then shares these files with other combatants through TADILs. Section 3 discusses the current shortfalls of TADILs in producing a common air picture among participants in the TADIL network. Moreover, track data may contain lapses when the sensors upon which the track is formed have diminished capability because of weather, environmental anomalies, or enemy jamming. The latency of air picture exchange, coupled with tracking lapses lead to ambiguities in developing a common air picture among combatants. As a result, operators spend a lot of time resolving these ambiguities rather than evaluating and acting on the information received.

The Cooperative Engagement Capability (CEC) has been developed by the U.S. Navy for the real-time exchange of fire-control quality data between shooters. Synonymous to the concept outlined in NCW, CEC uses *sensor netting* to generate an air picture that retains the critical data characteristics of accuracy and timeliness. This approach requires sharing radar measurement reports[84] from every sensor and takes advantage of the diversities of each combatant's sensors at different locations with varying features and capabilities.

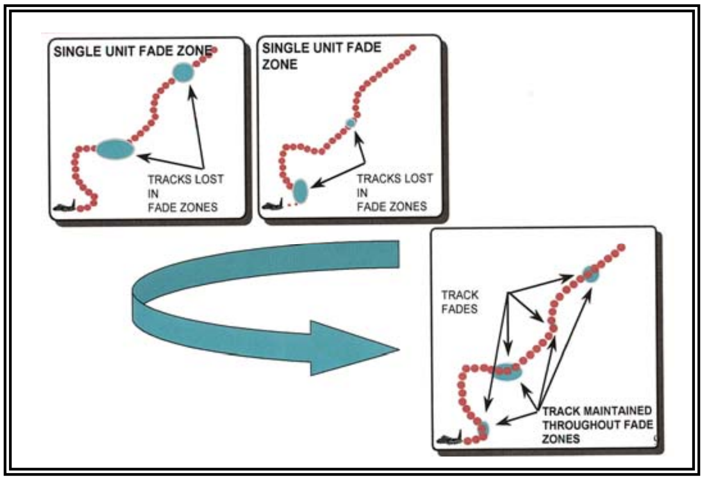

Figure 4-4 CEC Composite Tracking

The underlying principle in CEC is the concept of composite tracking. Consider Figure 4-4 where two independent sensors have two unique interpretations for a simple maneuver of a single aircraft. For one sensor, a track might start and stop due to terrain masking or environmental anomalies. Yet for another, tracking may be sporadic due to deliberate enemy jamming or evasive maneuvers. With CEC, fragmentary contact data available to individual sensors are combined to form a continuous track picture that is superior to what any single radar can produce.

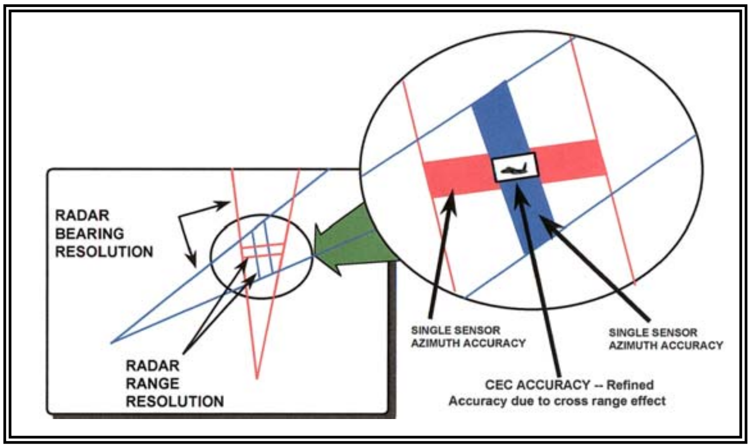

Figure 4-5 CEC Track Accuracy

Three significant warfighting benefits emerge from the simple, but powerful, concept of composite tracking. First, since radars are inherently more accurate in range than bearing, combining data from two distinct angles of view increases positional accuracy by taking advantage of cross range reduction in target location uncertainty. Moreover, as more radars contribute data from different angles, each report further enhances the target location and further reduces the uncertainty. Figure 4-5 illustrates increased track accuracy through composite tracking.

Second, composite tracking also increases track continuity. As shown in Figure 4-4, stand alone sensors do not track air targets continuously. Numerous variables impede a sensor's ability to maintain a continuous track. Such gaps in coverage produce fade zones where target tracking is temporarily inhibited. With CEC, track fragments from various radars are combined to form a continuous composite track. As a sensor loses detection and tracking in a fade zone, detections from other sensors "fill in" the voids and maintain the track through the fade.

Finally, improved track continuity and track accuracy equally contribute to the most important warfighting benefit derived from composite tracking: ID consistency. As discussed in Section 3, the erratic nature of TADIL tracking prevents the persistence of ID data on a particular track of interest. With CEC, the high degree of track continuity ensures that the ID attribute associated with a specific track remains with that target as long as it is in the J-IADS surveillance area. Moreover, CEC's increase in track accuracy also enhances ID continuity by allowing the radar to resolve targets with better granularity. In this way, combatants using CEC can distinguish individual targets even in close quarter maneuvering without the risk of track swaps that frequently occur in TADILs. Figure 4-6 depicts CEC maintaining ID consistency on proximal targets engaged in air combat maneuvers.

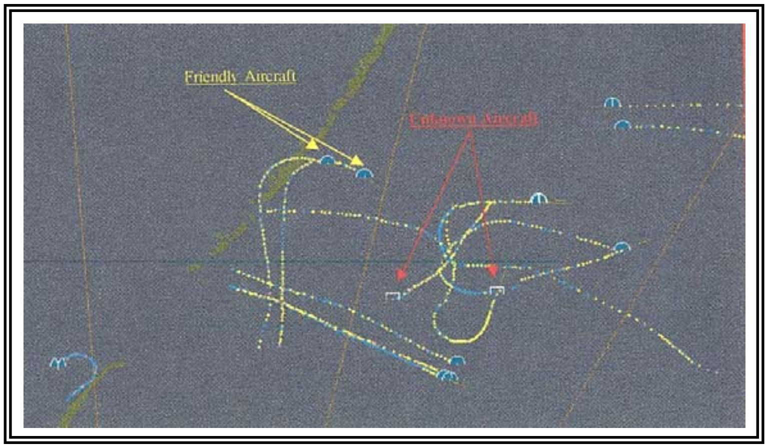

Figure 4-6 CEC ID consistency through
close quarter maneuvers and merges

The Marine Corps fully realizes the warfighting benefit generated by sensor netting. MARCORSYSCOM pursued a program to integrate the Marine Air Ground Task Force's (MAGTF) organic long range search radar, the AN/TPS-59(V)3, into the CEC network. The benefit of incorporating the AN/TPS-59(V)3 radar into the CEC network is noteworthy. The Marine Corps radar, optimized for detecting and tracking targets over land, complemented the Navy radars optimized for searching the sea echelon. The result is full battlespace surveillance and shared track picture for the entire force.

Perhaps most impressive is the *quality* of the air picture achieved by CEC through sensor netting. Unlike the picture produced by TADILs, CEC generates continuous, precise, and consistent track picture. However, CEC is as a weapons link designed exclusively to support engagements between dispersed missile shooters; it is not designed for situational awareness and conducting battle management. By design, CEC tracks alone lack the BMC^3 attributes necessary to form the SIAP.

The JDN, on the other hand, contains rich BMC^3 attributes but lack the tracking consistency achieved by CEC. Such findings, qualitatively and quantitatively measured in field exercises and experiments, form the foundation for MARCORSYSCOM's approach to building the SIAP. The approach centers on the notion that the SIAP may be attained by using the data provided by JCTN (CEC) as the kinematic base for the tracks and amplifying the track data with BMC^3 information available from the JDN and JPN.

JCTN(CEC) + JDN + JPN = SIAP

Figure 4-7 below graphically illustrates the notional information synthesis postulated in the above equation. In the figure, a correlation between JCTN (CEC), JDN (TADIL), and JPN (ELINT) track results in the optimal "compositing" of the information from each source. A selection process is used to determine the best attribute to draw from each data source. In this example, the high quality position and velocity state information is taken from the JCTN source, the identification (IFF) and track number attribute are taken from the JDN source, and the signal intelligence information is taken from the JPN source. The result is a single "composite" track containing the best attribute data from all sources.

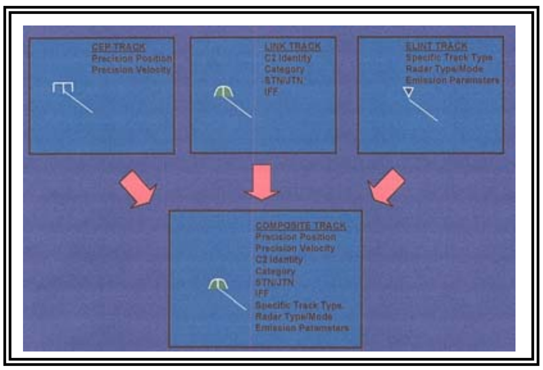

Figure 4-7 The SIAP construct

At the heart of the process is an information synthesis system – the Multi-Source Correlator/Tracker (MSCT).[85] The MSCT is built from mainstream commercial technology. The system is a set of computer programs written in the C++ programming language and runs on SPARC-based Sun Microsystem computers running the Sun Solaris

7.0 operating system. The system uses only standard local area network access network hardware and serial interfaces.

To produce a SIAP database from multiple data network sources, the MSCT performs correlation processing[86] on all tracks received. Since some tracks are provided only from a single source, the SIAP database is a combination of composite tracks and source tracks. Figure 4-8 illustrates the source and composite track relationship. In the figure, three source tracks (ST_A, ST_B, and ST_C) have been correlated to form a composite track (CT_1), while two source tracks (ST_D and ST_E) remain uncorrelated. Only the composite track is used to represent the three correlated tracks as a single entity; the two uncorrelated source tracks each represent two separate entities in the SIAP.

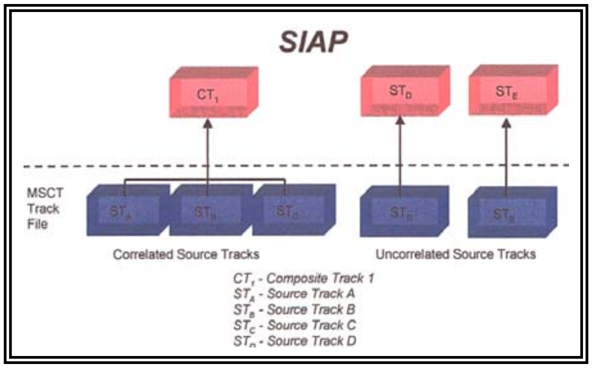

Figure 4-8 MSCT Correlation

The information synthesis process is carried out in several steps. Figure 4-9 depicts this multi-step process for fusing heterogeneous data elements. First, source track data are received from source interface (I/F) functions. The data are translated to form tracks and are stored in source specific sections of the track file (for example, SRC A track file). Source specific tracks are then compared to

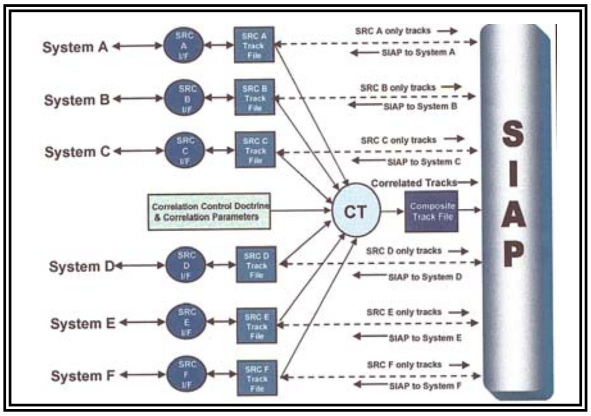

Figure 4-9 MSCT data synthesis

composite tracks and other source tracks to determine if relative positions indicate that the tracks may represent a single object in space. The comparison also determines whether any ID or other attribute information further supports or prevents track correlation into a single track. If a source track correlates with an existing composite track, the source track's information is combined with the composite track to further amplify the composite track. The source track is marked as "correlated" to prevent dual tracks from being transmitted to the display unit.

If a source track, however, is found to correlate with another source track, both sources are marked "correlated" and both track's data elements are combined to form a new composite track. In order to produce the SIAP, only uncorrelated source tracks and composite tracks are displayed[87]. Correlated source tracks are maintained in the MSCT master track file (CT) and are reprocessed when new source or update data is received to determine if the association has changed or whether new information indicates that the correlation is no longer valid.

A prototype battle laboratory was built by MARCORSYSCOM to test the SIAP hypothesis under field conditions. Figure 4-10 shows the battle lab, manned by Marines from the operating forces during a field deployment to Fleet Battle Experiment Charlie (FBE-C) in 1998. During FBE-C, the MSCT successfully produced a SIAP from a multitude of source track information from CEC and TADIL-J. Consider the example illustrated in Figure 4-11, below,

Figure 4-10 USMC CEC Battlelab

where two separate tracks appear to represent a single aircraft in the battlespace. The

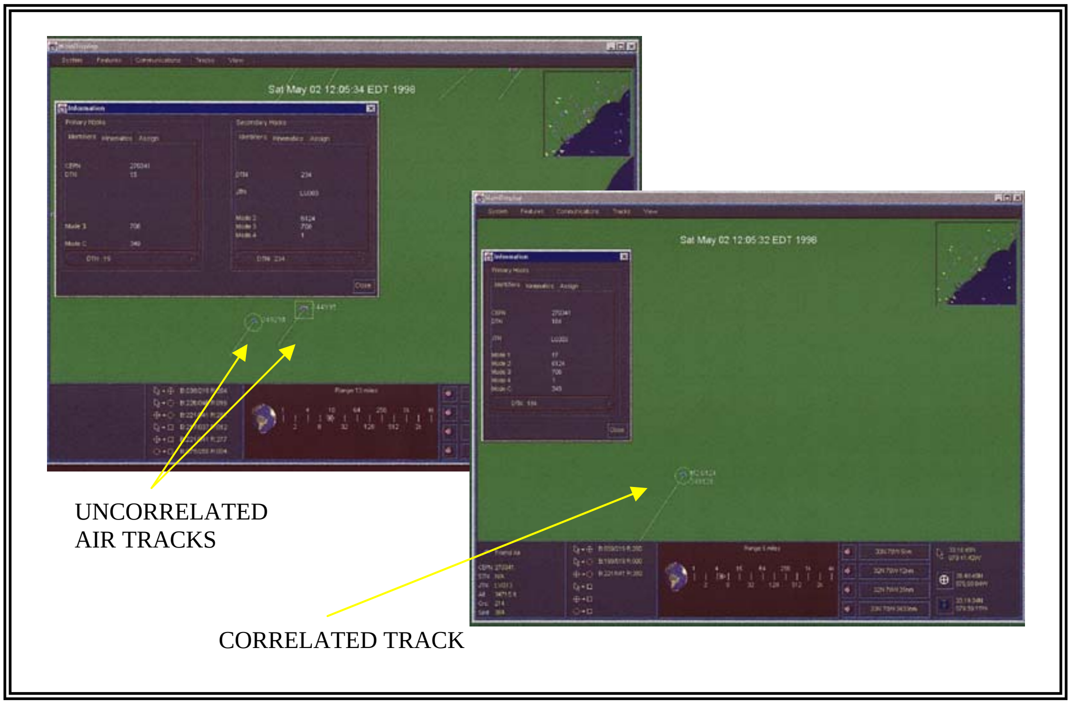

Figure 4-11 MSCT Correlation. The first screen shows two tracks representing a single target. The second screen shows the result of combing the track attributes of the two independent tracks to form an unambiguous track with superior position accuracy and attributes

leading track represents the CEC track with its superior position and location information. The trailing track is produced by TADIL-J and lags the true position of the aircraft (represented by the high-update CEC track) since TADIL-J reports the track up to 6 seconds later due to the nature of TADIL data transfer. When combined, the resulting "composite" track is far superior in attribute and accuracy compared to the individual source tracks and represents a portion of the SIAP.

The MARCORSYCOM experiment with SIAP proves that SIAP is achievable as articulated in the literature and theory. Although embryonic, the SIAP generated by the experiment is far enough along to stipulate that it is achievable and the payoff significant. The next section examines how the SIAP provides synergy to TAMD combatants by forcing interactions that allow all weapons and sensors to be used in a common battlespace to the full extent of their capability.

Section 5

Synergy

...the synergy of the Joint Force depends in large part on a shared understanding of the operational situation.[88]

-- Joint Pub 3-01,
Doctrine for Joint Operations

Collaboration in Battle

The American Heritage Dictionary defines synergy as "the action of two or more substances, organs, or organisms to achieve an effect of which each is individually incapable."[89] In the same manner, synergy occurs between TAMD combatants when their interaction creates a total effect that is greater than the sum of the individual effects. The Single Integrated Air Picture (SIAP) provides a new warfighting capability that defeats emerging technologically advanced threats through the synergistic integration of distributed resources among dispersed TAMD combatants. The SIAP generates synergy not by adding new sensors or weapon systems, but by using the information already existing in current TAMD systems to form a high quality track picture that is available to all combatants all the time.

The SIAP connects weapons, sensors, and C^2 decision systems from dispersed combatants into a single entity capable of collaborative action in battle. The SIAP among TAMD combatants alerts operators to what other combatants are doing, helps identify priority targets, recommends target-weapon pairings, and provides tactical warnings and advisories as the battle progresses. The intrinsic exchange of sensor and BMC^3

information between combatants through the SIAP allows dispersed combatants to exchange actions and intentions among each other. As such, the SIAP can be described as an integrated Sensor-BMC^3-Weapon System set of systems that is operational at all times.

SIAP Warfighting Benefits

The SIAP generates warfighting benefits to the JTF through the synergistic integration of distributed resources among its TAMD combatants. Specifically, the SIAP dramatically enhances the entire force's ability to detect, track, and engage even the most difficult targets by providing a coherent tactical picture that is available to all the combatants all the time. Warfighting benefits flowing from the SIAP include the extension of the entire force's battlespace to and beyond the horizon limits of individual sensors, better coordination of engagements and management of battle resources, and greater situational awareness over larger areas.

Expanding the Battlespace

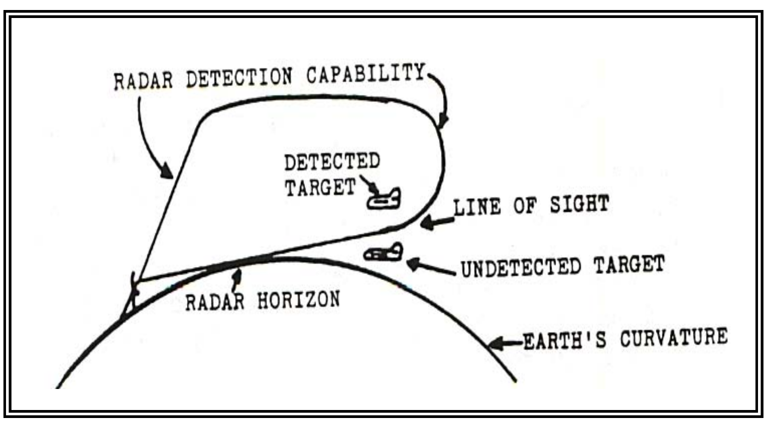

Figure 5-1 Effects of radar horizon on target detection

The sensor netting component of the SIAP allows for the extension of a combatant's battlespace beyond the horizon limits of its organic sensor. Although radar (electromagnetic) energy can propagate through space infinitely, it does so only by travelling in a straight line. As such, the line-of-sight property of radar energy restricts its range; the earth's curvature and terrain limit a radar's ability to detect targets beyond this "horizon."[90] Figure 5-1 shows the limits of radar detection as a function of the earth's curvature. However, the SIAP expands the force's battlespace by combining all of the combatants' individual surveillance areas. Consider the net effect of combining three sensor surveillance areas shown in Figure 5-2.

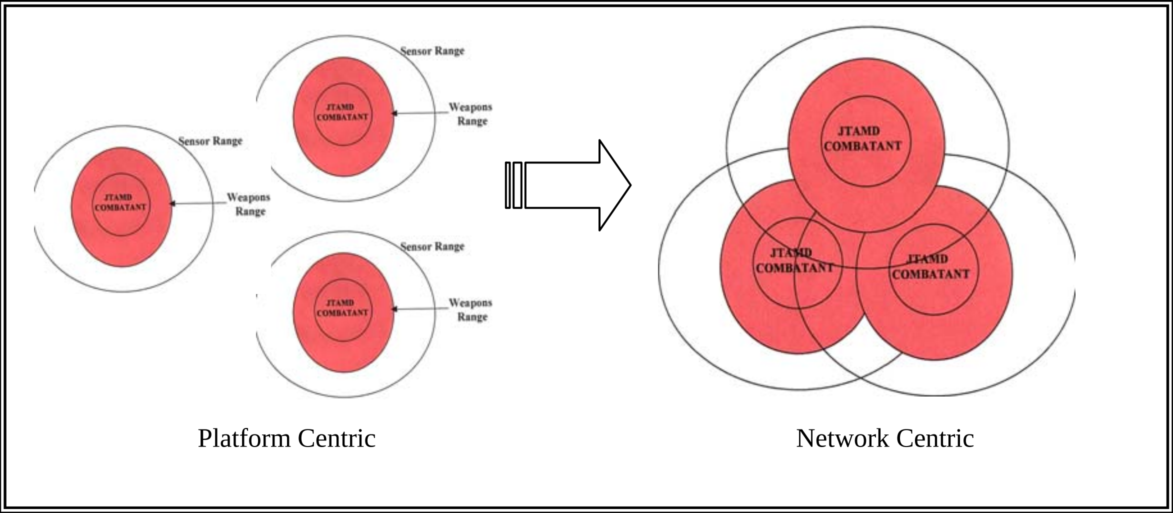

Figure 5-2 Extension of the battlespace through SIAP

Another way that SIAP expands the force's battlespace is by increasing the force's reaction time to theater air and missile threats. One combatant may "cue"[91] another combatant of an incoming threat well before the cued combatant acquires the target on its own organic radar because of radar horizon limits. In this way, a missile shooter provided a "cue" may engage a target at the maximum kinematic range of its weapon system and thus provides multiple engagement opportunities to assure destruction of the target.

Still another way that SIAP expands the force's battlespace is by enabling emerging integrated fire-control concepts that are impossible without the SIAP. Such concepts include *engage-on-remote* (EOR) and *forward pass*.[92] EOR and forward pass allow the maximum kinetic-range engagements by interceptor missiles. These concepts allow over-the-horizon engagements by surface units and leverage the firepower and range capabilities of current interceptors against low-observable theater missile threats. EOR and forward pass allow a shooter platform to remain EMCON[93] silent while using other combatants' sensors to detect a target and "guide" the missile to intercept. In this way, the SIAP allows a shooter platform to expand its battlespace; expanded battlespace generates increased reaction time allowing the shooter multiple engagement opportunities to destroy the threat. Figures 5-3A and 5-3B depict battlespace expansion through the prosecution of hostile targets by EOR and forward pass.

The EOR concept relies on the employment of non-organic sensors to provide fire control quality data upon which an engagement is conducted. As illustrated on Figure 5-3A, EOR engagement occurs when the initiation of an engagement against a threat is based on data received from a remote sensor before detecting the target with the shooter's own sensors. In this way, EOR

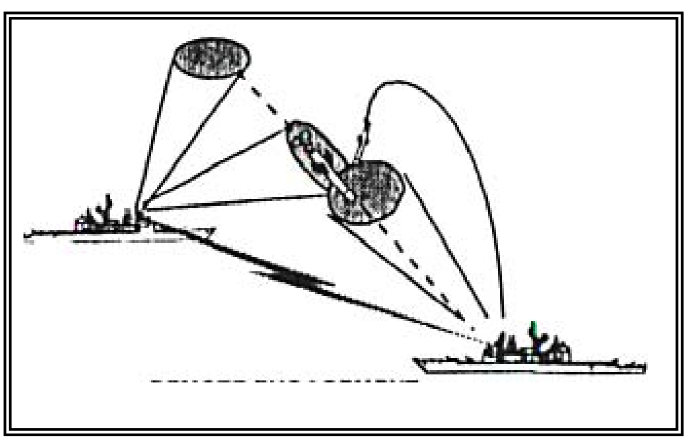

Figure 5-3A Engage on remote data

engagements overcome the fundamental horizon limitations of surface fire units against low altitude threats. Forward pass, depicted on Figure 5-2B, occurs when the execution of an engagement is based solely on remote data and terminal guidance of the missile is transferred to the remote data source. A forward pass is employed in situations where the organic sensor loses contact with the missile while it is in flight, or where the organic sensor is shut down after missile launch in an attempt to defend against an incoming anti-radiation missile.

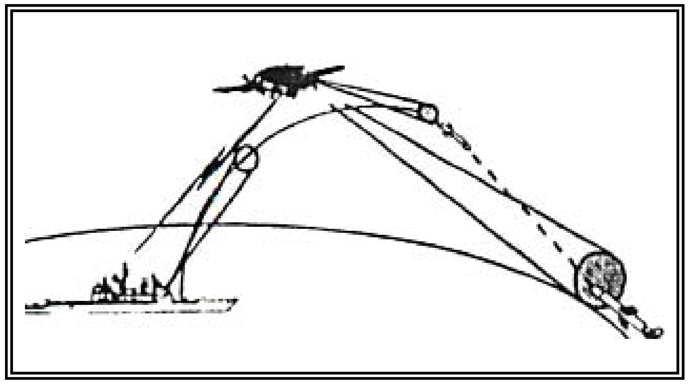

Figure 5-3B Forward Pass

Improving Engagement Coordination

Intrinsically, the SIAP generates synergy among TAMD combatants by enhancing coordination among shooters and C2 nodes in two ways. First, since all combatants have identical information about each target, all SIAP users are aware, in real-time, of the actions taken by other combatants against each hostile track. In this way, TAMD decision makers have confidence that they have an accurate, identical representation of the events occuring in the battlespace, thus precluding unncessary multiple engagements and conserving scarce resources. For example, without a SIAP, a Navy AEGIS Cruiser may engage a target that is simultaneously under attack by the Army's Patriot system. With both systems' firing doctrine[94] calling for two missiles fired at each target to ensure a high P_k[95], a handful of low cost cruise missile threats may quickly exhaust the finite amount of missile inventories in each combatants' magazine. Moreover, the high cost of technologically advanced interceptor missiles in the U.S. inventory today make the practice of uncoordinated engagements untenable and unsustainable.

A second way that SIAP enhances engagement coordination is by facilitating target engagement prioritization based on a common coherent track picture. The shared knowledge generated by the SIAP allows TAMD combatants to coordinate responses to engage targets that are most threatening to vital areas and defended assets. In this manner, TAMD combatants realize economy of force and are able to mass fire power although the combatants are geographically dispersed. Thus, coordinated engagements significantly increase the depth of fire and enhance mutual support of TAMD combatants.

Increasing Battlespace Awareness

Shared battlespace awareness begins with a relevant, common tactical picture at all levels. Once shared awareness is achieved, collaboration among the dispersed combatants naturally leads to a common understanding of the battlespace. This understanding, in turn, enables the force to act with shared intent and unified execution thereby generating synergy among the combatants. Furthermore, the SIAP ensures that every combatant in theater has an effective and coherent understanding of what has happened, what is happening, and what can happen. Coherence results in the harmony between each combatant's perception of the battlespace and is the cornerstone for synergy among TAMD combatants. Since the SIAP combines information from all nodes, it continually enriches the information base and serves to increase battlespace awareness.

The preceeding discussion presents the SIAP as a warfighting capability designed to more adequately meet and defeat the emerging threat through the synergistic integration of distributed resources and capabilities among dispersed TAMD combatants. The purpose of the SIAP is to **fight the Force as a single entity**, just as we now fight individual platforms. The SIAP seeks to enable real-time, synergistic response from the total force entity, improve the efficiency of TAMD operations, and provide resiliency and survivability of combatants. In essence, the SIAP seeks to enable the JTF Commander to better fight his force as a whole.

Conclusion

The SIAP brings about a significant change in TAMD by providing the capability to accurately portray the battlespace and engage increasingly challenging air and missile threats. It does so by generating an identical air picture, increasing detection ranges, producing consistent tracks, and promoting synergistic interaction between dispersed combatants. Such interactions generate warfighting benefits that effectively coalesce the collection of TAMD combatants into a single warfighting entity that can significantly improve the JTF's ability to deal with limiting cases of low radar cross section, environmental anomalies, classification and identification complexity, and current TADIL shortfalls. Each of these limiting cases seriously reduces the number of engagement opportunities available and the range at which engagements occur. However, the development of the SIAP can negate such cases; in fact, the synergy created by the SIAP, in most cases, regains the TAMD firepower and battlespace lost to emerging threat systems.

Joint Vision 2010 provides a coherent view of the future and its implication for joint operations expressed in terms of emerging operational concepts. It establishes "full spectrum dominance" as the collective goal and defines it as the "capability to dominate an opponent across the full range of military operations."[96] Achieving dominance over the proliferating theater air and missile threats requires the achievement of the SIAP among all TAMD combatants. As such, the SIAP supports the tenets outlined in Joint Vision 2010. First, the SIAP enables precision engagement by producing a consistent, accurate air picture that allows the engagement of hostile targets in proximity to friendly aircraft. This capability shifts today's isolated destruction zones, characterized by linear FEZs and MEZs, into a theater-wide Joint Engagement Zone where an air threat may be simultaneously engaged by more than one TAMD combatant. Second, the SIAP supports dominant maneuver by providing improved battlespace awareness. Precise knowledge of the location of the enemy air threat facilitates the movement of personnel and materiel throughout the battlespace. For example, the Joint Force Air Component Commander may route a strike package away from the enemy's combat air patrol station. Third, the SIAP supports full dimension protection by increasing the effectiveness of the JTF's air defense system. The increase in track continuity, track accuracy, and track continuity postulated in the SIAP ensures that theater missile threats are engaged at the maximum range of the JTF's air defense weapon systems. Finally, the SIAP conserves scarce resources (most notably Class V supplies) by eliminating redundant engagements. In this way, the SIAP indirectly eases the logistical requirements of the Force.

Notes

[1] U.S. Joint Chiefs of Staff, *Joint Vision 2010*, (Washington, DC:OJCS), p. 10
[2] Ibid., p. 16
[3] For example, the Army Tactical Missile System (ATACMS), the U.S. Army's centerpiece precision surface-to-surface weapon system against critical mobile targets, has a range of over 140km and is organic at the Army Corps level.
[4] Extending the Littoral Battlespace Advanced ConceptTechnology Demonstration (ACTD), *Proceedings of Common Tactical Picture Workshop One*, San Diego, California, 8-9 July 1998, (Arlington: Noesis, Inc., August 1998), p. 3
[5] Ibid., p. 3
[6] U.S. Joint Chiefs of Staff, *Joint Theater Air and Missile Defense Organization Charter*, (Washington, DC:JTAMDO), p.2.
[7] Joint Theater Air and Missile Defense Organization, *2010 JTAMD Vision Statement*, (Washington, DC:JTAMDO), p.3.
[8] Ibid., p.3.
[9] These threats include tactical ballistic missiles, cruise missiles, and unmanned aerial vehicles. Section 2 provides a more in depth discussion of these threats.
[10] Joint Pub 1-02, *DoD Dictionary of Military and Associated Terms*, defines real-time information as information which has been delayed only by the time required for electronic communication. This implies no noticeable delays.
[11] TAMD combatants refers to any agency within the Joint Integrated Air Defense System (JIADS). These agencies include surveillance platforms, shooter platforms, and command and control nodes.
[12] Balaisle RADM Philip, USN, "Keynote Address," Theater Air Defense Rountable, Naval Surface Warfare Center, Dahlgren, VA, May 12-13, 1998.
[13] In contrast to real-time data sources, near-real-time data has been delayed by the time required for electronic communication ***and*** automatic data processing. This implies that there are no significant delays.
[14] Joint Theater Air and Missile Defense Organization, *Capstone Requirements Document (CRD) for Theater Missile Defense*, (Washington, DC: JTAMDO, July 1998), p.5.
[15] Department of the Navy, *...From The Sea, Preparing the Naval Service for the 21st Century*, (Washington, DC:DON), p. 6.
[16] Gansler, Hon. Jacques, Speech at the Precision Strike Association Annual Program Review, Fort Belvoir, VA, May 19, 1998, downloaded from the Defense Link website: www.defenselink.mil/speeches/1998/gansler.
[17] United States Marine Corps, *Operational Maneuver from the Sea, A Concept for the Projection of Naval Power Ashore*, (Quantico, VA:MCCDC, July 1996), p.14.
[18] Ibid., p. 14.
[19] Ko, Harvey W., James W. Sari, and Joseph P. Skura, "Anomalous Microwave Propagation Through Atmosphereic Ducts," *Johns Hopkins APL Technical Digest*, Volume 4, Number 1, 1983, p. 12.
[20] All Services Combat Identification Evaluation Team, *ASCIET 99 Evaluation Report*, (Eglin AFB, FL: ASCIET), p.16-10.
[21] United States Marine Corps, *Marine Corps Warfighting Publication 3-25.7*, "Tactical Air Operations Center Handbook," (Washington, DC:HQMC, Sep 1996).
[22] The author observed track loads exceeding 400 tracks while conduction Developmental Test and Evaluation of a related TAMD system during Fleet Battle Experiment Charlie (FBE-C) held in the Virginia Capes Operations Area.
[23] Land based radars typically employ Moving Target Indicator (MTI) programs to cancel clutter returns from the environment. MTI removes radar returns that do not have the threshold velocity to classify it as a valid target. Additionally, radars may also employ pulse doppler wave forms to eliminate clutter. Simply stated, pulse doppler measures movement of contacts to or away from the sensor. No such movement indicates that the object is stationary.
[24] Ko, p. 14.
[25] Sensis Corporation, *Final Report/Recommendations for the Marine Corps Functional Interoperability System Test (MCFIST)*, (Syracuse, New York: Sensis Corporation, April 5, 1999), p. 1-8.

[26] Livingston, D.C., *The Physics of Microwave Propagation*, (Englewood Cliffs, New Jersey:Prentice Hall, 1970), p. 9.
[27] The maximum theoretical range of a radar is given by the maximum range from which an echo can return before the next suceeding pulse is transmitted. This range is a function of the radar's pulse repetition interval (PRI), the time required for a complete transmission cycle. The PRI is the time from the beginning of one pulse of RF energy to the beginning of the next. Extremely long propagation time of a radar's pulse due to ducting prevents the radar from receiving the reflected energy during its "receive" cycle within the PRI.
[28] Sensis Corporation, p.1-8.
[29] National Air Intelligence Center; NAIC-1031-0985-98, *Ballistic and Cruise Missile Threat*, p.2.
[30] Ibid., p.5.
[31] United States Army Air Defense Artillery School, *FY 99 Air and Missile Defense Master Plan (AMDMP*), (Fort Bliss, TX:USAADS, 1999), p. 2-3.
[32] Ibid., p.2-5
[33] Joint Requirements Oversight Council Memorandum 081-99, Memorandum for Commander in Chief, US Atlantic Command, 26 August 1999.
[34] Joint Pub 1-02, *Department of Defense Dictionary of Military and Associated Terms* defines the destruction areas the area in which it is planned to destroy or defeat the enemy airborne threat. The area may be further subdivided into fighter engagement zones (FEZ) and missile engagement zones (MEZ).
[35] Surface based air defense assets include all weapon systems from surface TAMD combatants. Such examples of surface based air defense weapon systems include the Navy's Aegis cruisers, destroyers, and the Army's PATRIOT missile system. The shoulder fired STINGER weapon system is also classified as a surface based air defense system.
[36] Leaker aircraft refers to unengaged threat aircraft that has penetrated the Joint Integrated Air Defense (J-IADS) primary destruction zones. Leaker aircraft threatening a TAMD combatant's self-defense airspace may be engaged under self-defense provisions in the rules of engagement.
[37] United States Joint Forces Command, *Capstone Requirements Document for Joint Tactical Command, Control, Communications, and Computers (C4) To Meet The Needs Of 2010 And Beyond*, (Norfolk, VA: USJFC), p.14.
[38] Wilson, CDR, Jeffrey W., USN, "Theater Air Defense Interoperability," briefing to the Joint Integrated Air Defense Ssystem Working Group, Fort Huachuca, AZ, 20 May 1998.
[39] "The Cooperative Engagement Capability", *Johns Hopkins APL Technical Digest* Volume 16, Number 4, 1995, p. 337.
[40] The TAOM "drops" a track after the radar fails to update its position after three rotations of the radar.
[41] JCS approved links include TADIL-J, TADIL-A/B, TADIL-C, ATDL-1, NADGE-1.
[42] Examples of proprietory links include the Marine Corps' Ground Based Data Link (GBDL) and Point-to-Point Data Link (PPDL) and the Army's Forward Area Air Defense (FAAD) Data Link (FDL).
[43] United States Department of Defense, *Joint Tactical Data Link Management Plan*, (Washington DC: DoD, 6 June 1996), p. ES-2.
[44] Ibid., p. ES-3.
[45] The J-series Family of Data Links is comprised of of data links that adhere to the basic message structure of TADIL-J (Link-16). Currently, TADIL-J and Variable Message Formats (VMF) are tactical data links that conform to this standard.
[46] Department of Defense, *Interface Standard, Military Standard 6016 (Mil-Std-6016), TADIL-J Message Standard*, (Washington, DC:DOD, 29 Jan 1995).
[47] Mil-Std-6016 contains more than 12 interim change proposals (ICPs) clarifying various ambiguous language in the standard. One ICP exists to amplify another existing ICP.
[48] Department of Defense, *Interim Change Proposal (ICP) TJ-95013 to Mil-Std-6016, TADIL-J Message Standard*, 29 Jan 1995 (Washington, DC:DOD).
[49] Johnson, LtCol Ronn C., USMC, "Autumn Events Data Analysis Group Results," briefing to the Director, Ballistic Missile Defense Organization, undated.
[50] JROC Memorandum, 081-99.
[51] ASCIET Final Report, p. 9-25.
[52] Ibid., p. 9-27.
[53] Ibid., p. 9-28.

[54] Lee, Edward, "Dual Net Multi-Frequency Link," briefing to Marine Corps Systems Command, Program Manager Air Defense, undated.
[55] ASCIET Final Report, p. 9-27
[56] Ibid., p. 9-30.
[57] Ibid., p. 9-30.
[58] Ibid., p. 9-32.
[59] BVR engagements refers to engagements conducted beyond the shooters ability to visually identify the target. BVR engagements require a high level of situational awareness and positive hostile identification indication. Current exercises and operations only allow BVR engagements if two or more external CID sources confirm that the suspect track is indeed hostile. Authority to engage targets BVR must be clearly articulated in the promulgated Rules of Engagement (ROE).
[60] White air refers to non-combatant aircraft in the theater of operation. The preponderance of white air are air vehicles performing commerce.
[61] United States Marine Corps, Operational Requirements Document for Combat Identification (CID), (Quantico, VA: MCCDC, 29 June 1998) , p.1.
[62] Marshall and Associates, *Combat Identification Study Final Report*, (Sterling, VA:Marshall and Associates), p. 2-1.
[63] Ibid., p. 2-1.
[64] NCTR systems allow the interrogating platform to recognize a target's identification based on a unique signature or attribute. For example, a TAMD combatant may detect a target's radar emission; the intercepted signal is then compared to a data base to associate a type of aircraft that may use the type of radar detected.
[65] Such specialized aircraft include the U.S. Air Force's RC-135 Rivet Joint for electronic warface missions. The RC-135 is capable of detecting air target signatures which it matches to a known data base of known attribute (electronic) signature to make an identification.
[66] For example, in ASCIET 99, the RC-135 did not have the capability to provide CID information into the TADIL network. TI operators aboard Rivet Joint used the Voice Product Net (VPN) to communicate the inforamtion to the TAMD command and control operators and shooters.
[67] Joint Theater Air and Missile Defense Organization, *Capstone Requirements Document (CRD) for Theater Missile Defense*, (Washington, DC: JTAMDO, July 1998), p. 6.
[68] U.S. Joint Chiefs of Staff, *Joint Vision 2010*, (Washington, DC:OJCS), p. 10.
[69] Different sensors may "see" the same target in a different manner for a variety of reasons. Limiting factors such as terrain and clutter may obscure one sensor's ability to detect a target; on the other hand, such limitations may have no effect on another radar. Frequency diversity amongst the different sensors contribute to the disparity in what the sensor may display. An X-band radar may behave radically different from a D-band radar and cause different probability of detection of targets at different ranges. Long duration, low frequency radars, for example are more suited for long-search missions while short duration, high frequency radars are more suitable for fire control tasks.
[70] Fire control quality means that the track generated (or received from another combatant) is such quality and fidelity that it can be treated by the receiving radar as if it was generated by its organic radar. Fire quality track reports allows a receiving unit to fire on a target within the kinematic envelope of its weapon system even though the unit's surveillance/acquisition radar does not "see" that target.
[71] Joint Pub 1-02, *Dictionary of Military and Associated Term*s, defines air superiority as "that degree of dominance in the airbattle of one force over another which permits the conduct of operations by the former and its related land, sea, and air forces at a given time and place without prohibitive interference by the opposing force."
[72] Alberts, David S., John J. Gartska, and Frederick P. Stein, *Network Centric Warfare, Developing and Leveraging Information Superiority*, 2nd Ed.(Revised), (Washington, DC:CCRP), p. 5.
[73] Gregory, Bill, "From Stovepipes to Grids," *Armed Forces Journal International*, January 1999, p. 18.
[74] Cebrowski, VADM Arthur K., USN, and John J. Garstka, " Network Centric Warfare: Its Origin and Future," *Proceedings of the Naval Institute* 124:1 (January 1998), p. 28.
[75] Joint Theater Air and Missile Defense Organization, *Battle Management Concept for Joint Theater Air and Missile Defense Operations in 2010*, (Washington, DC:JTAMDO, March 1998), p.34.
[76] Ibid., p. 36.
[77] BMDO Fact Sheet AQ-99-13, *Joint Composite Tracking Network*, January 1999, p. 1.

[78] U.S. Joint Chiefs of Staff, Chairman Joint Chiefs of Staff Instruction 3151.01, (Washington, DC: OJCS), p. GL-3
[79] Ibid., p. GL3-4.
[80] Capstone Requirements Document for Theater Missile Defense, p.8.
[81] While theCOP-CTP-SIAP pictures are ***all*** dynamically updated, the fundamental difference between the threee is the frequency of the updates. While the SIAP is concerned with track updates in sub-second frequency, the CTP updates only after several seconds have elapsed. In turn, the update rate for the COP may be several hours or days. In this way, tracks produced by the SIAP may not be displayed in the COP.
[82] Joint RequirementsOversight Council Memorandum 081-99, Memorandum for Commander in Chief, US Atlantic Command, 26 August 1999.
[83] Ibid.
[84] Radar measurement reports differ from track reports in that radar measurement reports contain raw position data (x, y, z coordinates and their accompanying acceleration components). Moreover, measurement reports are transferred directly to the tracker or data transfer mechanism. On the other hand, track based reports rely on the sending combat system to first establish a "firm" track, typically two or three "hits" on the radar, before the track is shared with other combatants. As such, the time period required to establish a firm track represents a substantial delay in communicating the track to other combatants whom might be interested in the track. In the case of a rotating radar at 6 RPMs, the delay is a substantial 18 seconds from the first time the sensor first detected the track of interest.
[85] The primary function of the MSCT is to receive tactical track information from multiple sources and produce a coherent, composite track database for display and dissemination. When displayed or communicated over TADIL, a subset of this track database represents the SIAP
[86] Correlation refers to a combat systems ability to resolve multiple tracks on a target. Differences in sensor alignment and lack of "gridlock" between combatants result in multiple reports on a single target. As it stands today, there is no universal correlation algorithm for combat systems that are agreed upon by all the services.
[87] An uncorrelated track is displayed since it represents a single object in space. On the other hand, correlated tracks are "combined" to produce a single composite track; the contributing tracks that lead to the composite track are maintained in the database in the event that the kinematic data is required to decorrelate the track.
[88] U.S. Joint Chief of Staff, *JCS Pub 3-01, Doctrine for Joint Operations*, (Washington, DC:OJCS).
[89] American Heritage Dictionary, 2nd Edition, (Boston: Houghton Mifflin Company,1985).
[90] The Line-of-Sight horizon for a radar may be calculated by the expression:
$LOS=(2h)^{1/2}$, where "h" is the antenna mast height in feet and LOS in miles downrange. From this expression one can derive the maximum detection range of the radar by the equation:
Max Detec Range (nm) (R) = $1.23 \text{ X } (H)^{1/2}+(h)^{1/2}$, where H= altitude of the target in feet, and h= height of the antenna mast in feet. Therefore, a radar with an antenna mast height of 25 feet can detect a target flying at 400 feet from 30.75 nm miles from the radar.

$R=1.23 \text{ X } (400)^{1/2}+(25)^{1/2}$

$R=1.23\text{X}25 = \underline{30.75\text{nm}}$

[91] Cue refers to one sensor's ability to provide direction to a weapon system or another sensor to optimize the cued unit's ability to detect and acquire a target. A surveillance radar may "cue" the fire direction radar of a TAMD shooter allowing the shooter to more rapidly acquire the target and hence expanding the reaction time for the shooter.
[92] Engage on Remote and EOR are target prosecution concepts possible with the advent of sensor netting. EOR is ability for a shooter platform to engage a target without "seeing" the target with its own radar. The initial guidance and mid-course correction for the missile in flight is retained by the firing unit but utilizes the data provided by another unit. Forward Pass refers to the ability of one combatant to fire a missile and hand-off the guidance of the missile to another platform to complete the engagement.
[93] EMCON stands for Emission Control, the selective and controlled use of electromagnetic, acoustic, or other emitters to optimize command and control capabilities while minimizing, for operations security, dectection by enemy sensors and minimizing mutual interference among friendly systems.
[94] Firing doctrine refers to a combatant's firing sequence to prosecute a target. For example, a combatant may employ a "shoot-look-shoot" to first assess the effectiveness of the first shot. Another example of

firing doctrine is the "shoot-shoot-look." In this technique, the combatant fires to successive missiles to increase the probability of hitting the target.

[95] P_k (probability of kill) refers to the probability of a missile (weapon) destroying its intended target. P_k is normally expressed as a value between 0 and 1. A missile with a P_k of .9 refers to a 90% probability that it will destroy (kill) its intended target.

[96] U.S. Joint Chiefs of Staff, *Joint Vision 2010*, (Washington, DC: OJCS), p. 26.

GLOSSARY

AOR	Area of Responsibility
AP	Anomalous Propagation
ASCIET	All Services Combat Identification Evaluation Team
ASD(C3I)	Assistant Secretary of Defense for Command, Control, Computers, and Intelligence
ATO	Air Tasking Order
AWACS	Airborne Warning and Control Squadron
BMC3	Battle Management Command, Control, and Communications
BVR	Beyond Visual Range
CAT	Clear air turbulence
CEC	Cooperative Engagement Capability
CID	Combat Identification
COP	Common Operational Picture
CTP	Coherent Tactical Picture
C2	Command and Control
DODD	Department of Defense Directive
EMCON	Emission Control
EOR	Engage on Remote
FBE	Fleet Battle Experiment
FEZ	Fighter Engagement Zone
GCCS	Global Command and Control System
GPS	Global Positioning System
GRIS	Global Reconnaisance Information System
ICP	Interim Change Proposal
ID	Identification
I/F	Interface
I-JWCA	Interoperability Joint Warfighting Capablities Assessment
INS	Intertial Navigation System
JCTN	Joint Composite Tracking Network

JDN	Joint Data Network
JEZ	Joint Engagement Zone
JFACC	Joint Force Air Component Commander
JFC	Joint Force Commander
JIADS	Joint Integrated Air Defense System
JITC	Joint Interoperability Test Command
JOPES	Joint Operational Planning and Execution System
JPN	Joint Planning Network
JROC	Joint Requirements Oversight Council
JTAMD	Joint Theater Air and Missile Defense
JTAMDO	Joint Theater Air and Missile Defense Organization
JTDMP	Joint Tactical Data Link Management Plan
JTF	Joint Task Force
JWCA	Joint Warfighting Capability Assessment
MAGTF	Marine Air-Ground Task Force
MARCORSYSCOM	Marine Corps Systems Command
MEZ	Missile Engagment Zone
MSCT	Multi-source Correlator Tracker
NCW	Network Centric Warfare
NCTR	Non-cooperative Target Recognition
OSD	Office of the Secretary of Defense
P_k	Probability of Kill
RCS	Radar Cross Section
SA	Situational Awareness
SIAP	Single Integrated Air Picture
SORTS	Status of Resource and Training System
TADIL	Tactical Digital Information Link
TAOM	Tactical Air Operations Module
TBM	Tactical Ballistic Missile
TEL	Transporter, Erector, Launcher
TI	Target Identification
TTP	Techniques, Tactics, and Procedures
UAV	Unmanned Aerial Vehicle
VACAPES	Virginia Capes

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