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# A C2 System for Future Aerospace Warfare

**Bonnie W. Young**
Joint Single Integrated Air Picture System Engineering Organization (JSSEO)
Northrop Grumman
2611 Jefferson-Davis Highway Suite 8000
Arlington, VA  22202
(703) 407-4531ph
Bonnie.Young@ngc.com

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Bonnie.Young@ngc.com

**Abstract**

Future advances in Joint aerospace warfare depend largely on Network-Centric Warfare (NCW) solutions that enable new and enhanced forms of Command and Control (C2). The role of C2 in aerospace operations is to optimize the use of offensive and defensive resources to combat aerospace threats. NCW-enabled C2 will enhance time-critical aerospace operations by enabling the use of *distributed* warfare assets in collaborative missions that optimize their use for Force-level priorities. A primary example of a collaborative C2 capability is Integrated Fire Control (IFC) or the tactical engagement of aerospace threats using distributed warfare assets. Selecting the best shooter from a set of geographically distributed firing units improves the chances of intercepting targets (by selecting optimal engagement geometries) and improves the economy of weapon resources (by eliminating multiple redundant shots). For complex threat environments in which many aerospace targets exist, collaborative fire control may be a necessity for victory.

This paper introduces advanced Joint aerospace C2 concepts for the 2015 – 2025 timeframe. The advanced C2 capabilities are built on a NCW foundation of information superiority—shared, accurate, and timely situational awareness. The integrated architecture and common processing (behavior model) that comprise the NCW foundation for aerospace operations are the core capabilities of the distributed system known as the Single Integrated Air Picture (SIAP). The SIAP distributed system is currently under development by the Joint SIAP System Engineering Organization (JSSEO). This paper summarizes the SIAP distributed system in order to lay the NCW foundation upon which advanced forms of Joint C2 are built. This paper then presents advanced concepts for the future such as distributed resource management, Automated Battle Management Aids (ABMA), advanced IFC, collaborative planning, enhanced situational awareness, and Effects Based Operations (EBO).

## 1.0 Network Centric Warfare Foundation

Advanced forms of collaboration among distributed Joint warfighting units require a basic NCW foundation comprised of an information architecture that promotes information sharing among distributed units and processing resident at each unit to enable shared knowledge. This section presents the integrated architecture and approach currently taken by JSSEO that will provide a NCW foundation for future Joint C2.

The JSSEO is developing a Peer Computing Program (PCP) (also known as the Integrated Architecture Behavior Model (IABM)) that resides on each "peer" or participating Joint warfighting unit. The SIAP "system" is really a set of distributed PCPs interacting in a collaborative manner over the Peer-to-Peer (P2P) network. Figure 1 illustrates the distributed SIAP "system" consisting of multiple peers interacting in an operational scenario context and interfacing with external non-SIAP entities. An individual peer is shown as a single PCP and associated warfare resources. Host units (or warfighting units) are operational platforms such as ships, aircraft, land-based assets, or other that play a role in aerospace operations.

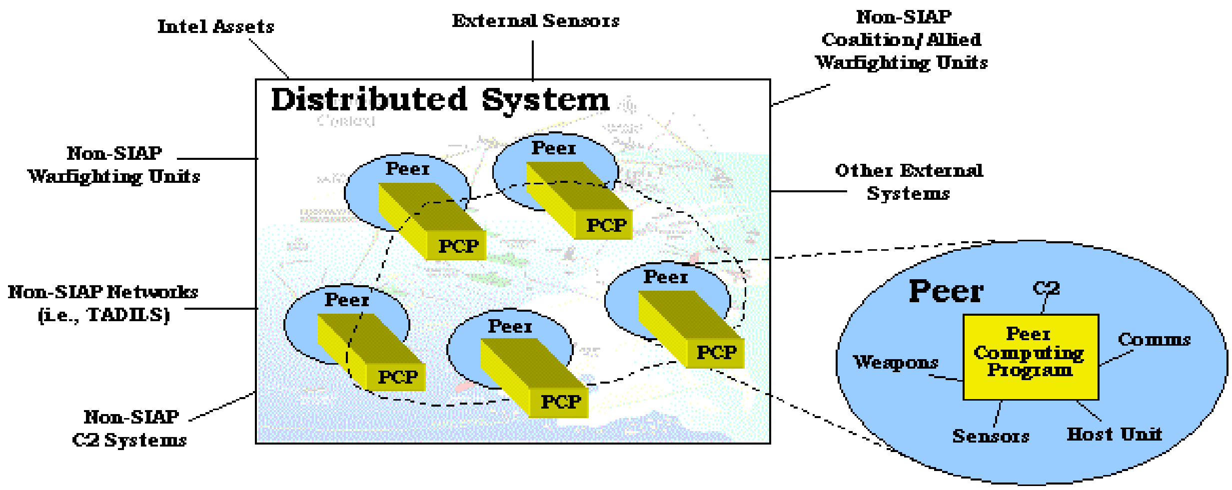


**Figure 1 - SIAP Distributed System Context Diagram**

Each PCP contains common processing—identical computational and algorithmic methods. This supports the "SIAP common processing" philosophy, illustrated in Figure 2, upon which the SIAP concept is based. The philosophy, simply stated, is that identical PCPs provided with identical sets of data/information input will produce identical picture, assessment, and decision results.

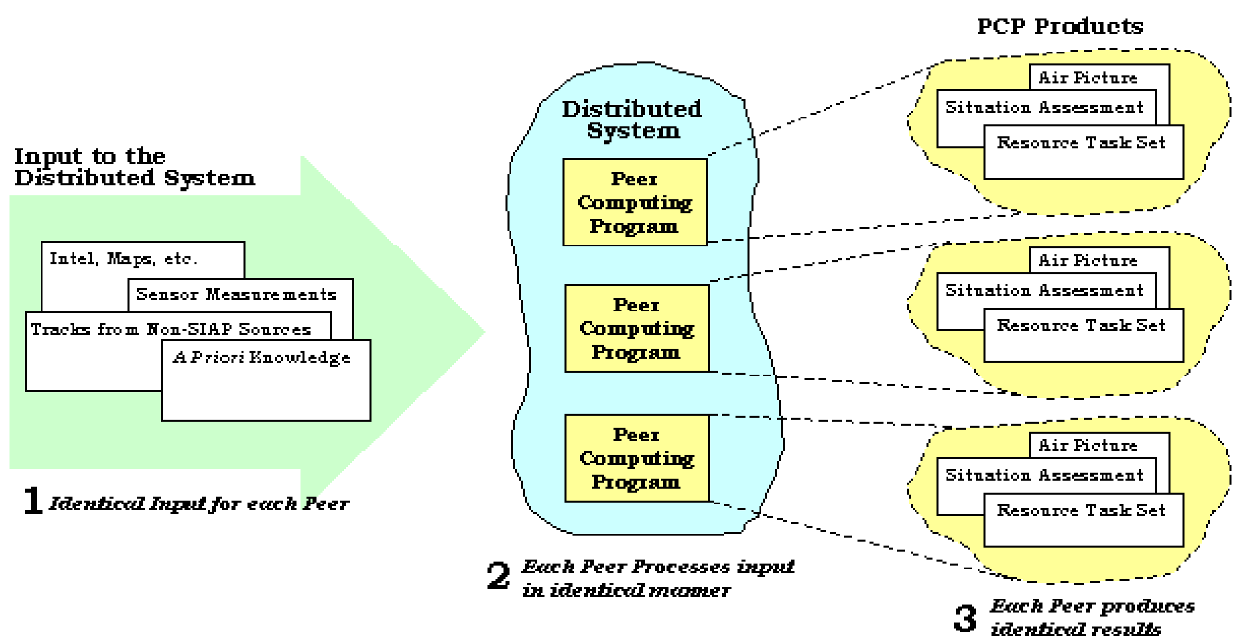


**Figure 2 – SIAP Common Processing Philosophy**

### 1.1 Core Peer Computing Program Capabilities

The core PCP capabilities function to create the SIAP—the air portion of the Common Tactical Picture (CTP). The SIAP consists of common, continual, and unambiguous tracks of airborne objects of interest in the surveillance area. The picture is derived from real time and near real time data, and consists of correlated air object tracks and associated information (such as Combat Identification (CID) information).

Figure 3 shows the external interfaces of a single PCP unit. PCPs interface with a warfighting unit's resident sensors, weapon systems, relevant operator displays, and C2 systems. PCPs interact with each other over the Peer-to-Peer (P2P) network communications architecture. PCPs communicate with other systems (warfighting units without PCPs, C2 systems, etc.) over Link 16 or Link 11.

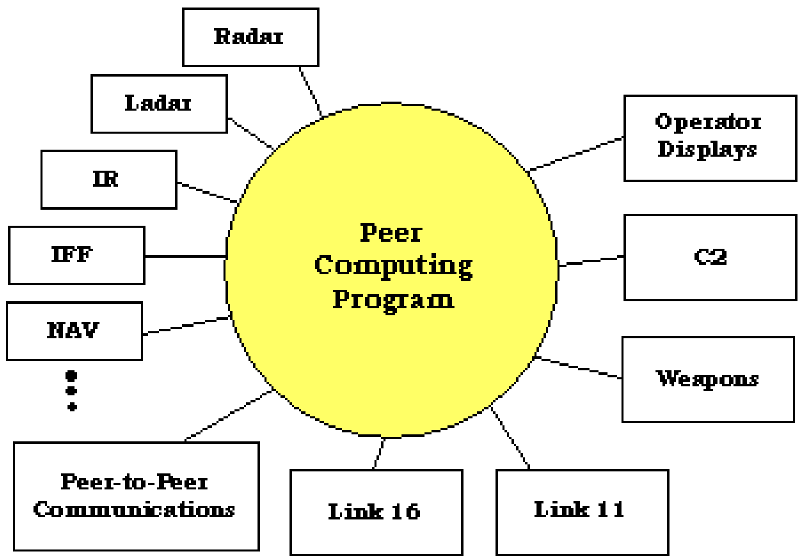


**Figure 3 – PCP Context Diagram**

The PCP is an executable digital model that fuses near real time and real time data, scaleable and filterable to support situation awareness, battle management, and target engagement. The core capabilities of the PCP include target detection, target tracking, and target identification. The core PCP functions are responsible for: 1) receiving and transmitting sensor measurement data (Associated Measurement Reports (AMRs)) among PCP units, 2) processing the sensor data to generate the single integrated air track picture, and 3) making CID determinations for each aerospace object in the track picture.

Figure 4 illustrates the PCP architecture for Configuration 05 – the first intended production of the PCP software. Track management, as shown in the Figure, will contain functionality to fuse sensor data and associate data with tracks already held or create new tracks when required. The track management design reduces the risk for dual tracking, track blooming, and tracking conflicts. The tracking process ensures the capability for multiple PCP units to create and maintain a consistent, timely, and accurate track picture identical for all users. Data is fused from PCP and non-PCP equipped units to produce and associate air tracks within the operational environment. Using common algorithms, PCPs will arrive at a single track and CID determination.

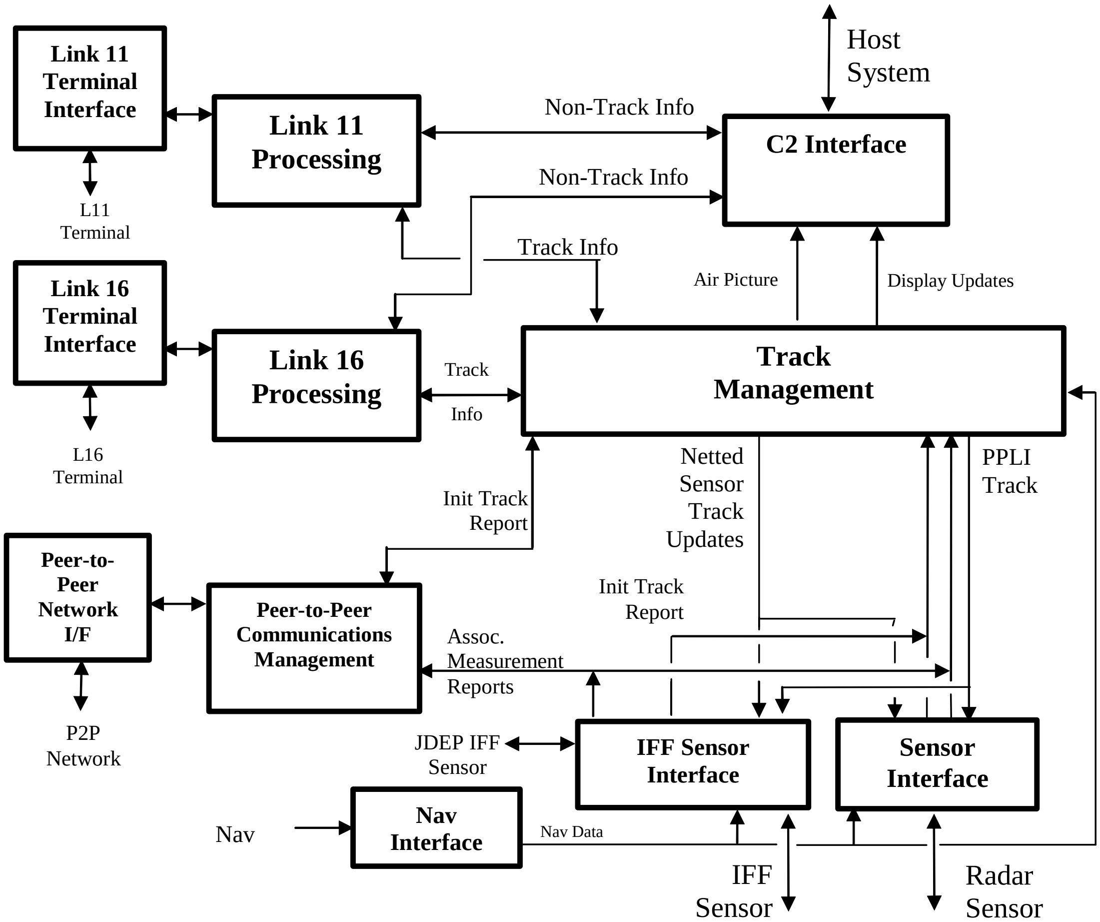


**Figure 4 – PCP Core Architecture**

The IABM CID process will provide accurate and consistent characterizations of aerospace objects in the operational environment to enable rapid, high confidence decision-making. The CID process will use common algorithms, within each PCP, that fuse relevant CID indicators. PCPs will associate indicators and air track data sets to provide accurate, common, and consistent characterization of aerospace objects in the battle space. Once an initial CID determination has been made, PCPs will continue to refine CID characterizations with indicator updates as they become available. CID determinations will include: UNKNOWN, ASSUMED FRIEND, FRIEND, SUSPECT, HOSTILE, and ASSUMED HOSTILE.

## 1.2 Information Architecture

While individual PCPs provide organic capabilities, the real force multiplier is when they are netted together in a mutually supportive role—providing a battle space awareness that is greater than the sum of their individual awarenesses. A set of distributed PCPs function collaboratively to develop a SIAP among participating units. This is achieved through the establishment, maintenance, and management of P2P networks that enable a data dissemination capability necessary to support the SIAP objectives.

The reality of warfare operations is that at any given time, warfighting units may be collaborating on various levels based on their collaboration needs as well as their ability to collaborate. Their collaboration needs may range from autonomous operations (or the complete lack of collaboration); to the sharing of tactical information and development of a single integrated air picture; to highly integrated operations involving the commitment of warfare assets to a collaborative warfighting operation involving multiple distributed units. The ability to collaborate depends on adequate communications and data paths between distributed units as well as embedded PCP functionality that manages the necessary distribution of data/information and enables the decision-making capabilities and collaborations to occur.

The core SIAP capability is based on the P2P network, which enables the sharing of tactical data, or AMRs, among peers. Key to generating the SIAP is the sharing of data in an unprocessed or raw form to take full advantage of data fusion and tracking algorithms resident in the PCPs. Figure 5 illustrates this point.

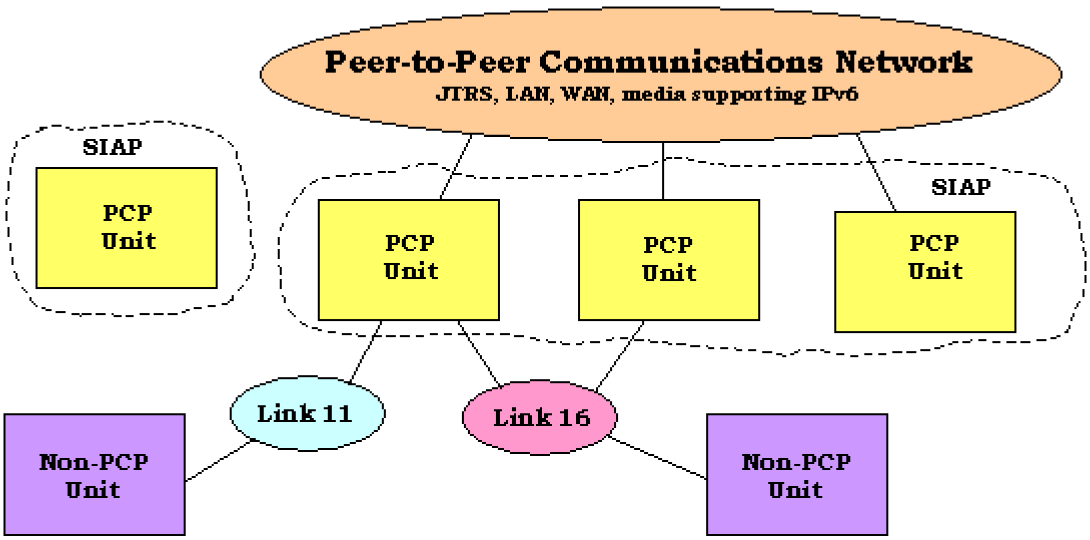


**Figure 5 – SIAP Information Architecture Examples**

Figure 5 shows an example architecture among warfighting units. Three PCP units are collaborating via the P2P network. One PCP unit is operating in a stand-alone mode—not connected to any other units. Two units without PCPs are connected to other units via Link 11 and 16. The result is that two separate "SIAPs" (air pictures resulting from PCP processes) exist in this scenario. The stand-alone PCP generates its air picture with data from organic sensors. The three PCPs collaborating over the P2P network generate a common SIAP. The non-PCP units may generate air pictures using their resident tracking processes; however, commonality between their pictures and the SIAP of the 3 PCPs is not guaranteed. The tactical data links share tracks, or already-processed data, rather than sensor measurements in a more raw form. This constrains the data fusion/processing that is possible and integral to the SIAP peer process.

The P2P network in development to support the core PCP functions is conducive to supporting future advanced Joint C2 capabilities. Future C2 concepts, based on advanced data fusion techniques, require data in a raw or unprocessed form. Dissemination of measurement data is one of the key features of the P2P network. Future C2 concepts will require additional information sets to be shared among peers. Examples include: information concerning the status, location, and configuration of warfare resources (sensors, weapons, warfighting units);

environmental data sets; imagery; and C2 datasets (plans, direction, tasking, doctrine, rule-sets, etc.) Therefore, the P2P information architecture must support the transmission of large amounts of data in a timely fashion. Another key feature of the P2P information architecture is that it supports decentralized distributed C2, which is critical for laying a NCW foundation for advanced C2 capabilities, for time-critical aerospace operations.

**2.0 Concepts for Future Joint C2**

The basic premise of the SIAP concept is the "Common Processing" philosophy whereby if a set of distributed PCP-equipped warfighting units each receives identical data sets and uses common data processing algorithms; each will construct a common track picture. This premise is carried one step further in support of future Joint C2. Equipping each PCP with common decision-making algorithms, which when fed identical track pictures (or data sets), allows each to produce identical resource tasking recommendations.

For example, each PCP unit can use "common" algorithms to produce identical Force-level engagement recommendations at each participating node. Therefore, each PCP unit will near-simultaneously arrive at the same conclusion that a particular weapon has the best shot and that a particular sensor (not necessarily collocated with the weapon) can best track and/or illuminate the target. This concept relies on incorporating common automated decision aids into each PCP and implementing an architecture that enables the sharing of common data sets and information among PCP units.

The two key PCP capabilities that support future Joint C2 concepts are:

(1) To automate the attainment of shared, accurate, and complete situational awareness of the battlespace and
(2) To automate the decision-making process involved in most effectively managing warfare assets (resources).

This section proposes capabilities that build on the core SIAP PCP functions and integrated architecture to enable new and enhance existing Joint C2. The proposed additions to the PCP core are automated decision-making and advanced data fusion algorithms. These capabilities will enable each PCP unit to operate in an automated and coordinated fashion to produce identical Force-level decision recommendations and enhanced situational awareness or information superiority. This section explores concepts that support operational capabilities in which warfare resources can be optimally managed from a collaborative perspective.

Figure 6 shows a diagram of the proposed functions that could be automated and performed by each peer to produce identical decision recommendations and management aids. The functions are loosely based on the data fusion construct developed by the Joint Directors of Laboratories (JDL). Figure 6 identifies areas within the peer concept that align with the JDL levels of data fusion. The figure shows entities external to the peers such as sensors, weapons, decision-makers, Intel/weather data sources, and the warfighting units to which peers are resident. The diagram does not show communications interfaces or peer functionality involved in communications. This paper focuses on the proposed data fusion and decision-making functionality that could be embedded in each PCP. These advanced functions will require enhanced information exchange capabilities—but this subject will be addressed in future papers.

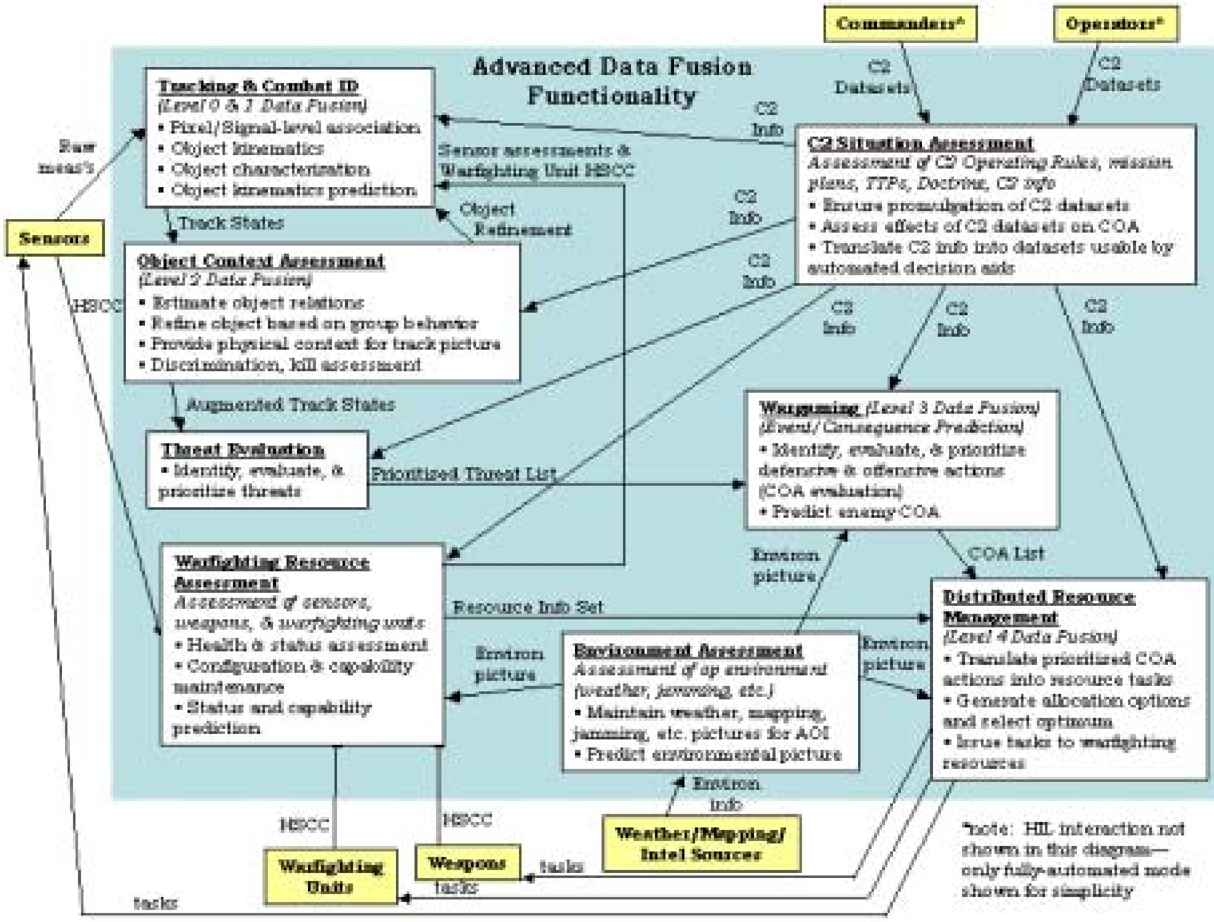


**Figure 6 – Future PCP Functionality**

The core PCP functions comprise the "Tracking and Combat ID" function set shown in Figure 6. These functions provide the basic air picture upon which the rest of the advanced functionality shown in Figure 6 relies. The tracking and CID functions constitute levels 0 and 1 in the JDL model (shown in Figure 7). Level 0, or Sub-Object Data Assessment is the estimation and prediction of signal/object observable states on the basis of pixel/signal level data association and characterization. Level 1, or Object Assessment, is the estimation and prediction of entity states on the basis of observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID).

Several of the function sets shown in Figure 6 provide situational awareness—object context assessment, threat evaluation, warfighting resource assessment, environment assessment, and C2 situation assessment. These function sets are all described in more detail in Section 2.1. They are grouped together because they all support the development of a higher level of awareness of the operational situation by fusing or associating non-kinematic data sets with the track picture. The object context assessment capability is most similar to JDL level 2 data fusion. Level 2, or Situation Assessment, is defined as the estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc.

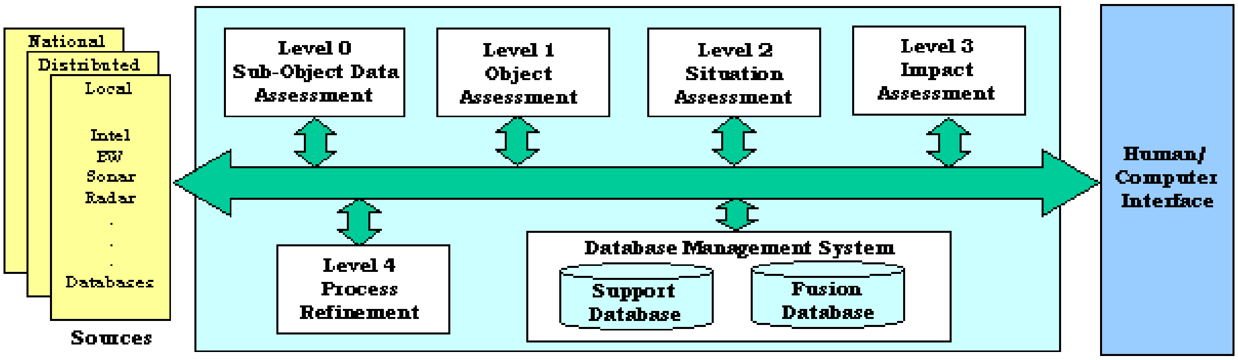


**Figure 7 – JDL Levels of Data Fusion**

The function set, “Wargaming”, shown in Figure 6 represents functions that predict future operational situations. This set of functions is described in Section 2.2 of this paper. The functions are similar to the JDL level 3 type of data fusion—impact assessment. Level 3 data fusion is the estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants; to include interactions between action plans of multiple players (e.g. assessing susceptibilities and vulnerabilities to estimated/predicted threat actions given one’s own planned actions).

The key capability for enabling advanced Joint C2 for future aerospace warfare is the function set labeled “distributed resource management” in Figure 6. This function identifies tasks that need to be performed based on Force-level mission needs and allocates them to warfighting resources using optimization techniques. This function set is effectively the culmination of all the other function sets shown in Figure 6—relying on the results of all of their processes. Distributed resource management (DRM) is the subject of Section 2.3 of this paper. DRM is most similar to JDL’s level 4 – process refinement. JDL defines process refinement as adaptive data acquisition and processing to support mission objectives. DRM, as proposed in this paper, encompasses adaptive data acquisition—effectively sensor resource management, as well as addressing the adaptive management of weapons and warfighting units.

## 2.1 Advanced Situational Awareness/Assessment

Situational Awareness (SA) is the act of understanding the totality of the tactical situation, including the threat, the defended assets, the readiness of warfighting resources, and command and control constraints within which the systems must operate. SA within the SIAP context is the ability of the collective peers to share a common understanding of the operational situation. In the case of a stand-alone peer, its SA is confined to what it can produce using the information available to it.

SA includes the common understanding of the following aspects of the operational situation. There are various aspects of the operational situation that comprise SA. Each peer will effectively create and maintain a “picture” of each of these aspects (listed and described in Table 1). The pictures are really sets of information that are products of the data fusion process. Each picture will contain a set of information that is updated on a continuous basis to most accurately reflect the real state of the battlespace situation.

**Table 1 – SA Aspects of the Operational Situation**

| SA Pictures | Descriptions |
|---|---|
| Track Picture | The track picture is comprised of track data and CID information that represents aerospace objects. This fundamental information forms the core foundation for PCP capabilities. |
| Object Context | This set of information contains estimates of group behavior of aerospace objects. This information may be used to modify values in the track picture. For example, a CID designation of an individual object may be established or modified based on the object's behavior in relation to other object behaviors. |
| Threat Picture | The threat picture contains information regarding the set of aerospace objects deemed to represent enemy targets. The picture contains the identification, evaluation, and prioritization of threat objects |
| Defended Assets Picture | This picture contains the location and status of all defended assets (ground, maritime, and aerospace). It includes all defended aerospace objects and zones as well as points or areas on the ground within an area of interest. PCPs assign a "defense level" or prioritization based on established doctrine and/or operator input. The purpose of keeping track of all defended assets on the surface is to feed into the process of prioritizing threats and determining the best course of action (including determination of best shooter and/or intercept location) based on the defense of blue forces, Allies, and friendly civilian areas. |
| Warfighting Resources | The warfighting resource picture is comprised of location, Health, Status, Configuration, and Capability (HSCC) information of each warfare resource (sensors, weapons, and warfighting units). This information will be used to best manage the resources and formulate resource tasking. |
| Environmental Picture | This picture is comprised of information regarding the environment of the relevant battlespace. It may contain meteorological, electromagnetic jamming, and atmospheric information. It is used in more advanced techniques for refining the ability to certify data quality and tracks based on environmental effects on sensors; and tasking sensors based on the optimum use in different environments. |
| C2 Situation | Decision-maker commands, assigned missions of warfighting units, doctrine, Tactics Techniques and Procedures (TTPs), location and status of IABMs, status of P2P network |

The set of functions that develop SA are data fusion, association, and assessment processes that develop a description or interpretation of the current relationships among aerospace objects, events, and the context of the operational environment. This process estimates the operational situation and assigns quantitative confidence values to the estimates. Effectively, the functions seek to develop as accurate a representation of the real world as possible. Quantitative values are computed to allow decision-makers to know with what confidence a particular object is a threat or what the probability that a particular weapon system will engage a threat, as examples. The point of automating the situational assessment capability is that the complex and time-critical nature of operational situations for aerospace warfare can involve the assimilation of large amounts of information in time periods that are too narrow for manual assessment to support rapid and effective decision-making. Performing such assessments on distributed warfighting units to support collaborative operations compounds the challenge. Embedding common situational assessment functions in a network of distributed PCPs that can share data and information is the concept explored in this section.

This section discusses some of the major situation assessment functions that support the achievement of situational awareness. Figure 8 shows a diagram of these functions.

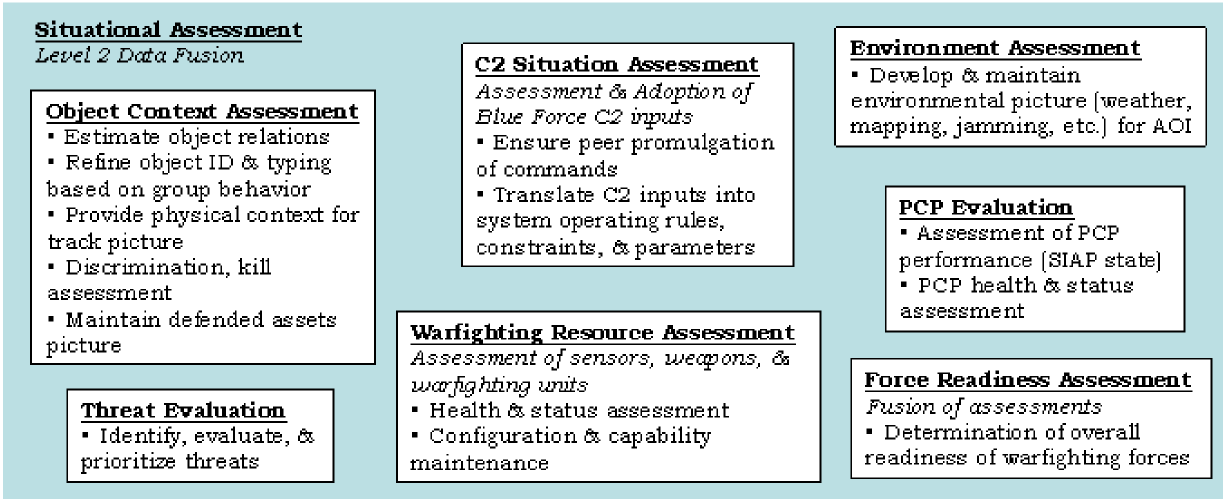

**Figure 8 – Situational Assessment Functionality**

Thus, while the core PCP processes focus on the existence of aerospace entities such as enemy aircraft, cruise missiles, and ballistic missiles; situation assessment focuses on interpreting the meaning of these entities (i.e., to determine the military order of battle and the existence of high-level military organizations). These techniques are drawn from automated reasoning and artificial intelligence.

**Object Context Assessment**

Object context assessment examines the group behavior of aerospace objects and the operational context of aerospace objects. It estimates and predicts relationships among entities to include force structure, cross-force relations, communications, perpetual influences, and physical context. The input to this functional domain includes track datasets or states on a "per object" basis and types of C2 dataset information applicable to providing operational context to the area of interest. Prior to object context assessment, each object has been examined individually—the kinematics and characterization have been assessed for each individual aerospace object. Within the object context assessment domain, the kinematics and characterization of the group behavior of a set of aerospace objects is assessed. And from this assessment, individual object characterizations may be refined and additional information concerning objects may be attained. For example, a ballistic missile in the deployment phase may produce multiple aerospace objects including a re-entry vehicle and many discrimination objects (chaff, penetration aids, etc.). The group behavior of the deployment objects will be assessed to produce a discrimination assessment to distinguish the re-entry vehicle from other objects, predict the impact point, and further characterize the threat.

Object context assessment also develops an estimate of the operational context. This involves developing and maintaining a database of information concerning the operational environment to include, for example: geography of the area of interest (AOI), points of interest, nation borders, no-fly zones, and locations of defended assets. An example is the creation and maintenance of the defended assets picture. PCPs will receive defended assets information from the tracking and CID domains (i.e., friendly aerospace objects), from the warfighting resource evaluation domain (i.e., the location of blue forces or friendly warfighting units – ships, aircraft, land-based sites, command centers, etc.), and from C2 datasets (defended nations, assets, Allied forces, defended Areas of Responsibility (AORs), defended buildings or point locations, etc.). PCPs will maintain a defended assets database and will assign relative values to the assets that indicate priority or defense criticality.

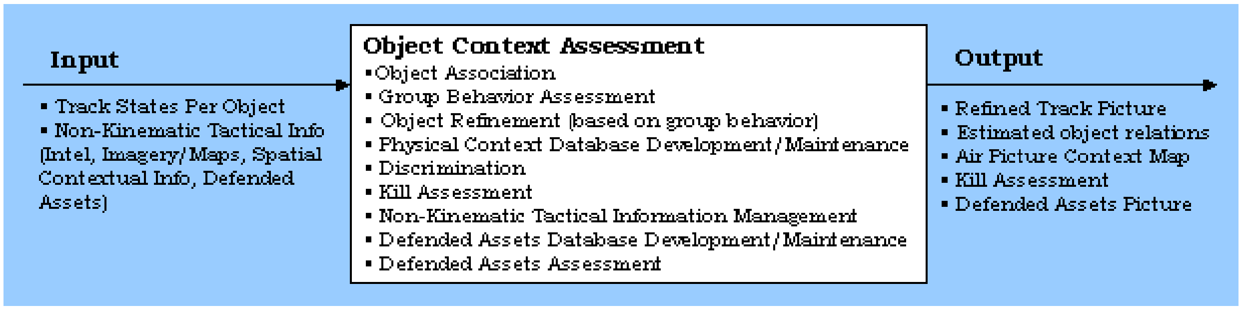


**Figure 9 – Object Context Assessment**

Figure 9 shows the functionality of object context assessment as well as the input and output. This set of functions has been grouped together because they support the attainment of knowledge of the operational situation or battlespace. However, this set encompasses a varied and complex group of algorithm and methods. The following table contains high-level descriptions of the object context assessment functions.

**Table 2 – Object Context Assessment Functions**

| Function | Description |
|---|---|
| Object Association | Object association develops hypotheses for associations among aerospace objects. Associations among objects are estimated based on relationships including temporal relationships, geometrical proximity, communication links, and functional dependence. Examples of object associations include: a set of tracked aerospace objects representing ballistic missile deployment phase targets and penetration aids; a set of tracked objects representing a squadron of fighter aircraft; and a set of blue force aerospace objects that are part of the defended assets picture. |
| Group Behavior Assessment | Group behavior assessment assesses the behavior of a hypothesized group of associated objects. Assessments include group and object characterization by comparisons of the kinematic behavior to templates. Also includes event/activity aggregation, which establishes relationships among diverse entities in time to identify meaningful events or activities. |
| Object Refinement | The refinement or modification of a particular aerospace object's characterization or identification based on the results of group behavior assessment. |
| Physical Context Database Development | The development and maintenance (updating) of a database or "picture" of the operational situation based on the fusion and association of the track picture with non-kinematic tactical information. This capability also includes contextual interpretation/fusion, which provides an analysis of an individual aerospace object's or group's relationship with the evolving contextual situation including weather, terrain, sea-state or overland conditions, enemy doctrine, and socio-political considerations. Context correlation fuses multi-source (kinematic, ID, parametric and geographic) information. |
| Discrimination | Discrimination refers to the set of algorithms and methods involved in distinguishing the re-entry vehicle in a complex missile threat from chaff and penetration aids. |
| Kill Assessment | Kill assessment assesses the effectiveness of an intercept of an enemy aerospace object based on real-time sensor input (i.e., kinematic change, change in signature). Related functionality includes: engagement status tracking (which monitors the |

| Function | Description |
|---|---|
| | progress of the current engagement situation) and battle damage assessment (which analyzes post-engagement and offensive action data to determine the effectiveness of blue force battle damage inflicted on red forces or red force defended assets). |
| Non-Kinematic Tactical Information Management | "Non-Kinematic Tactical Information" includes tactically-relevant information that is non-kinematic and of a non-sensor-processed nature. It may include intelligence, imagery, voice data, and context information (e.g., commercial air and shipping lanes, political and cultural boundaries (observed countries of threat origin and countries of over flight, etc.), geographical items of interest, etc.). This functionality manages and fuses this information into forms that support tactical operations. |
| Defended Assets Database/Assessment | This functionality develops a defended assets "picture" within the area of interest that includes all defended aerospace objects and zones as well as points or areas on the ground. A "defense level" or prioritization is assigned based on established doctrine and/or operator input. The purpose of keeping track of all defended assets in the air and on the ground is to feed into the process of prioritizing threats, which ultimately supports the optimized use of warfighting resources. The defended assets information set can also be displayed to operators and commanders in order to allow them to easily change prioritizations as necessary. This information set also supports wargaming functions, which evaluate proposed blue and red force courses of action. |

## Threat Evaluation

The threat evaluation function determines what aerospace objects are candidates for engagement or defensive action, determines whether engagements or actions are allowed, and assigns relative priorities to those aerospace objects designated as threats. Threat evaluation depends directly on track characterization processes and track kinematics. Track characterization processes determine track category (e.g., space or air), type (e.g., SCUD-B, M-9, F-16), and identification (e.g., friendly, hostile). "Common" threat evaluation (CTE) means that doctrine has a force-wide scope, processing considers multi-source information, and procedures are implemented in an identical or functionally equivalent way among coordinating peers. The objective of CTE is to provide consistent threat designations and priorities across a distributed system of peers.

Threat evaluation comprises doctrinal procedures that are based on prevailing rules of engagement or defensive action. Threat evaluation may be separated into the processes for threat assessment and threat prioritization. Threat assessment includes determining what aerospace objects are threats and whether engagements or defensive actions are allowed. Threat prioritization assigns relative priorities to the threats.

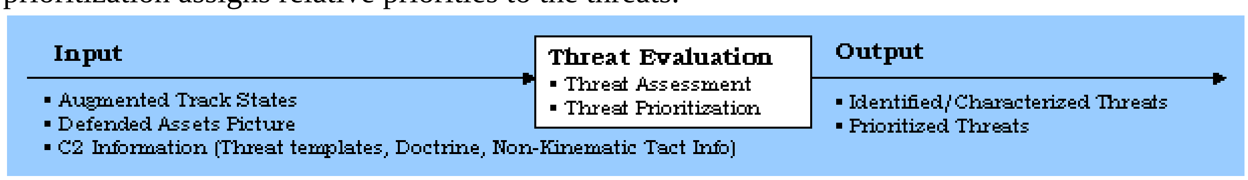


**Figure 10 – Threat Evaluation**

Figure 10 shows input and output to the threat evaluation process. Input consists of augmented track states that include track characterization (track category, type, and ID information), the target's kinematic profile (e.g., diving, climbing), and overt behavior (e.g., associations with known hostile forces, reported jamming activity, targeting maneuvers, reported Radar Alert Warnings, etc.). Non-kinematic tactical information for threat evaluation includes collected artifacts (images), Intel threat cues, observed enemy information, observed over flights, etc. The defended assets picture and C2 information are used to determine whether defensive actions are possible. Intercepts may not be possible in Fighter Engagement Zones (FEZs) or over protected friendly assets on the ground.

Threat assessment provides the capability to evaluate and determine the threat situation. It utilizes position and kinematics information (track states); combat ID information; selected overt behaviors exhibited by an object's track; track history; and non-kinematic tactical information (from the C2 dataset) such as intelligence data to evaluate the threat relative to area, force, and defended assets.

Threat prioritization provides the capability to prioritize threats based on fused object attributes from multiple sources. It maintains and updates an identical force-wide prioritized threat assessment information set. A threat priority level is assigned to each threat using the kinematic profile and proximity and time to impact relative to the prioritized defended assets. Engagement priority is determined for aerospace threat objects. The threat list associates known threats with all possible defended assets that may be affected. The threat value relative to each defended asset based on the probability of occurrence and potential severity or consequence is assessed and maintained. Additionally, it computes a relative threat value for the degree to which each defended asset is threatened by a potential aerospace object threat.

**Warfighting Resource Evaluation**

The evaluation of warfighting resources is the management of information concerning sensor, weapons, and warfighting units as well as the assessment of their capabilities in particular operational situations. Figure 11 lists the major functions of warfighting resource evaluation and as well as the input and output to this function set. "HSCC" refers to information set concerning each resource that includes: health, status, configuration, and capability.

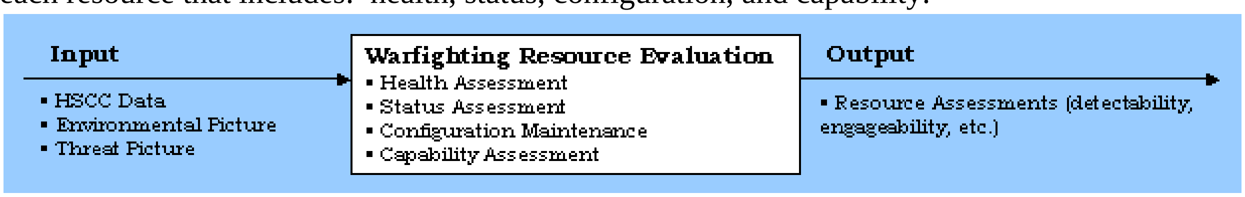


**Figure 11 - Warfighting Resource Evaluation Functionality**

The evaluation of warfighting resources requires HSCC data from the resources as well as the environmental picture, the threat picture, and resource task sets. The HSCC data from each resource is shared among peers on a continuous basis much like AMRs are shared. Table 3 provides a description of each of these types of resource information sets.

**Table 3 – HSCC Information**

| HSCC Dataset | Description |
|---|---|
| Health | Information regarding a resource's ability to perform optimally. (For example, a sensor's health data may include its current registration, alignment, and calibration information as well as information regarding whether its operation is degraded.) |
| Status | Information regarding a resource's current tasking and thus, availability for future tasking. |
| Configuration | Information regarding a resource's mode and configuration. (For example, a resource may be on, off, in standby, etc.; additionally a sensor may be in a search or track mode, etc.) |
| Capability | A static information set that includes a resource's capabilities (functional and performance) and limitations based on various environments, configurations, and threats or tasks. |

Warfighting resource evaluation is performed by each peer in a distributed system so that each peer will gain a high level of awareness concerning the abilities of all participating resources. This important capability is a critical part of developing effective and timely resource tasking for Force-level missions. Each peer assesses the health or quality, availability or status (based on current tasking/mission), and configuration of each resource. Each peer then assesses resources ability to fulfill operational missions based on their capabilities and current locations and situations. In the case of multiple resources that are able to support a mission, such as engaging a threat or surveilling a region, the system prioritizes resources based on their capabilities and determines which individual or group of resources should be assigned. Quantitative confidence values are computed for each assessment.

Additionally, the overall readiness of the Force can be assessed based on the assessments of the individual warfighting resources. This computation may provide desired information to Force-level decision-makers.

**Command and Control Situation Awareness**

C2 situation awareness is the capability to maintain a shared awareness among PCPs of command orders from various levels in the warfighting chain of command involved in battle management and force command. Basically, it involves the creation of a picture or awareness of the current C2 situation. The C2 situation could be considered an "overlay", in a sense, on the battlespace that is changing as operations develop over time. The C2 picture focuses mainly on the state of affairs of friendly forces and warfighting resources. It depicts the deployment or mission status of units—showing aircraft on strike missions or land or sea based units in surveillance modes, for example. It may flag units that have command authority over other or are operating covertly. It will show the status of peers—which are operating as a distributed system and which are stand-alone. It shows the status of the information architecture—any outages or non-P2P links, for example. It shows the status of current plans and shortfalls in compliance.

**PCP Evaluation**

PCP evaluation is the ability of a set of distributed peers to monitor the individual and group performance of a peer or set of collaborating peers. The performance of PCPs and PCP collaborations constitute an important aspect of the operational situation. For example, any degradation in the PCP's ability to develop and maintain an accurate track picture and situational awareness will affect the ability to effectively use warfighting resources for operational objectives. Assessment of the "SIAP state" is the evaluation of all PCP system components and products (track picture, other pictures, etc.) to support appropriate adjustments of components necessary to optimize PCP products. This includes discrete comparisons of the current state against design quality objectives and changing user needs; as a continuous process. Other self-assessments include: the P2P network, information assurance, and PCP operations.

### 2.2 Situation Prediction/Wargaming

Situation prediction is the projection of the current situation into the future to estimate the enemy course of action (COA) and potential impact of the Force's planned actions. Situation prediction is performed using automated management aids (AMA) to predict real-time, near real-time, and non-real-time operational situations based on blue and red hypothesized COAs. The current situation, as developed by the various situation assessment and evaluation functional sets, is projected into the future to assess inferences about alternative futures or hypotheses concerning the current situation and possible COAs.

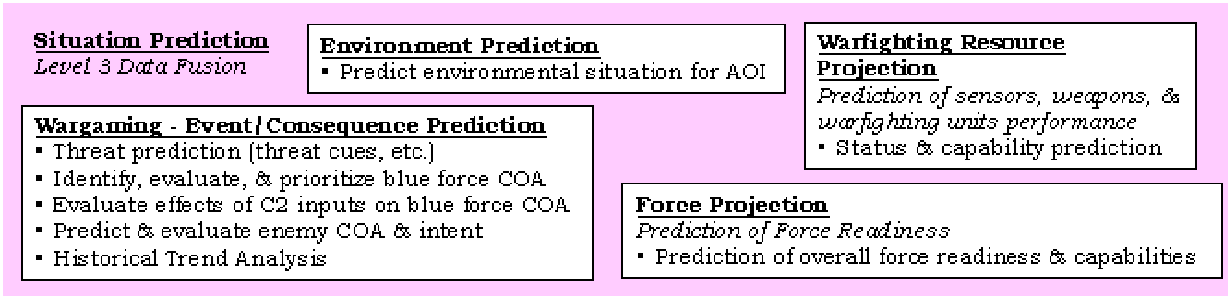


**Figure 12 – Situation Prediction Functionality**

The functions that comprise situation prediction, as shown in Figure 12, include environment prediction, warfighting resource projection, wargaming, and force projection.

**Environmental Prediction**

Environmental Prediction produces Meteorological and Oceanographic (METOC) weather forecasts based on current and historical conditions. This capability links weather predictions with weapon and sensor thresholds to determine the feasibility of employing specific munitions and sensor detection ranges. The analysis includes the use of wind, cloud, precipitation, and temperature data. The analysis also predicts the environmental impacts from munitions employment. The results of environmental prediction can be used in support of planning blue force COAs—environmental effects may be taken into account in projecting future resource capabilities (i.e., weather affects on sensors, aircraft, ships, etc.).

**Warfighting Resource Projection**

The projection of warfighting resource capabilities into the future based on hypothesized COAs is an important part of wargaming. This function set maintains an information database of resource capabilities in various operational and environmental conditions.

**Wargaming or Event/Consequence Prediction**

The ability to predict enemy COAs provides great advantage to the warfighter. Assigning quantitative confidence values to potential COAs will support other advanced C2 capabilities such as collaborative planning and resource management. For example, based on the confidence level of a predicted enemy Theater Ballistic Missile (TBM) launch site, PCPs may assign a priority level to the site as a possible future threat. This function then feeds the resource management capability by building a case for increased sensor surveillance of the region or a possible assigned strike mission. Examples of enemy COA attributes that can be predicted and assessed are described in Table 4.

**Table 4 – Enemy COA Attributes**

| Enemy COA | Description |
|---|---|
| TBM Launch Site | Prediction of launch site locations and types based on launch point estimations of tracked TBMs. |

| | |
|---|---|
| TBM Launch | Prediction of future TBM launches (launch type, time, direction) based on known and estimated parameters and capabilities of the launcher (from previous launches, Intel, a priori knowledge, estimated time of mobility of the transport-launching container, etc.) |
| Enemy Attribution | Prediction that attributes a particular hostile event or object to a particular enemy. This is particularly important for terrorist activity—predicting which nation or terrorist group is responsible for a hostile action. |
| Enemy Intent | Determination of enemy intention based on actions, communications, and enemy doctrine. |
| Enemy Capability | Estimation of the size, location, and capabilities of enemy forces |
| Threat Opportunities | Identification of potential opportunities for enemy threat based on prediction of enemy actions, operation readiness analysis, of friendly vulnerabilities, and analysis of environmental conditions. |
| Enemy Scenarios | Develop a battlespace visualization of the national guidance and assigned regional area of responsibility (AOR) to create enemy scenarios and enemy courses of action. From this visualization, at the component-level, targeting analysis, situation assessment, target development and selection, target nomination, weaponeering, and Battle Damage Assessment (BDA) can be accomplished. |

Predicting enemy COAs forms the basis for wargaming hypothesized blue force COAs. Future PCPs could have embedded wargaming functionality that enables them to identify and evaluate tactical options for near real-time defensive responses or offensive actions; as well as plan blue force COAs for longer projected time periods such as hours to weeks ahead. Thus, this future capability would bridge the gap between tactical operations and planning capabilities; enabling dynamic replanning and allowing warfighting resources to be used most effectively based on the most current knowledge of the operational situation.

Wargaming functionality includes multi-perspective analysis, which analyzes current and predicted operational situations from both red and blue perspectives. Offensive/defensive analysis predicts the results of hypothesized enemy engagements considering rules of engagement (ROE), enemy doctrine, and weapon models. The wargaming would take into account estimated weapons effectiveness based on projected weapon resource capabilities. Wargaming functions calculate effectiveness measurements such as: probability of kill, probability of raid annihilation, probability of survivability, and probability of munitions effectiveness. These projected measures of effectiveness would support the estimate of projected force readiness. Wargaming could enable PCPs to support Effects-Based Operations (EBO) in which the effects of our actions on the enemy would be analyzed and assessed to support decision-making. The wargaming functionality produces prioritized blue force COAs that supports the generation of missions and tasks for use by the distributed resource management process.

### 2.3 Distributed Resource Management

The benefit of implementing a SIAP across Joint forces lies in the new capabilities made possible by enhanced information sharing and information commonality between distributed warfighting units. Foremost is the potential to enable the distributed collaborative use of warfare resources to support real-time critical mission areas. This section explores this SIAP-enabled application—distributed resource management (DRM).

The DRM concept relies on viewing a set of warfighting units as a single integrated and interoperable combat system of systems rather than a collection of loosely connected surface, subsurface, and air platforms. Such force level thinking shifts the focus from autonomously operating systems with little or no collaboration incentive to optimized and automated uses of resources (sensors, weapons, communication networks, and units) that transcend unit boundaries and span multi-threat dimensions. This capability relies on implementing distributed and dynamic resource management functions in an automated fashion to support Joint decision-making among units.

The DRM automates and optimizes the management of warfighting resources. The key feature of DRM is the enabled capability for a Joint force of participating warfighting units to manage their resources cooperatively. The concept relies on equipping peers with automated management algorithms that compute optimum resource allocations for all of the resources in the Joint force and then synchronize the allocation. The theory supporting DRM is based on the idea that once the SIAP is achieved among a group of warfighting units, the units can collectively use this shared battlespace omniscience to more effectively manage assets in an automated fashion.

The DRM relies on all the other function sets shown previously in Figure 6. For input, the DRM capability requires results of situation assessment and situation prediction. The DRM must identify a running list (that is continually being updated as the operational situation changes) of specific tasks (or resource missions) based on the identified and prioritized threats, best estimated blue force COA, and operational situation (i.e., environment, defended assets locations, etc.). Figure 13 shows the DRM functions as well as the input and output to this function set.

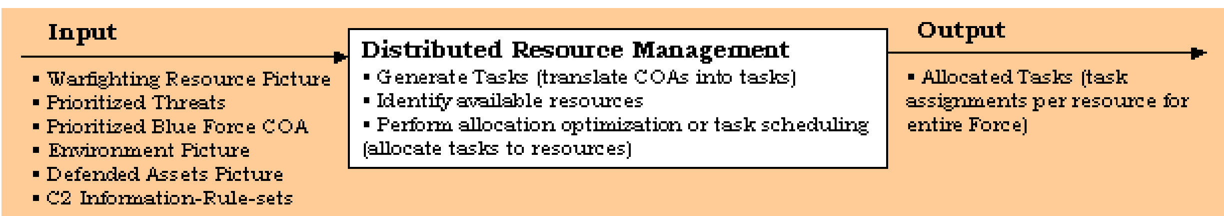


**Figure 13 – DRM Functionality**

The DRM uses optimization techniques to schedule tasks or allocate them to the most suitable warfighting resources. Based on the availability and capability of resources at any given time, the DRM may have to modify the list of tasks and determine that some cannot be performed or may be performed in a different order. The advantage of the DRM capability is that it enables each distributed peer to determine the best use of each resource in the "force" (or within a set of collaborating peers) and to make this determination in a near-simultaneous manner. In this way, resources can be used for force needs rather than just for the needs of an individual unit. Figure 14 shows how the resource picture of a single peer that is operating in a stand-alone mode contains only the HSCC of the resources on that unit; while a set of interacting peers share HSCC information and enable each peer to develop a force-wide resource picture that contains the HSCC of all the participating resources within the force.

The resource picture has several uses that include:

- Providing necessary information for the optimal allocation of tasks to a single unit's resource or a set of distributed resources;
- Providing resource capability information to support wargaming and collaborative planning;

- Providing an additional form of combat identification—sharing HSCC data of warfighting units (aircraft, ships, etc.) over the P2P serves as a form of blue force CID;
- Providing sensor health information for the assessment of measurement quality to determine whether measurements should be fused into the track picture; and
- Providing the means to assess sensor degradation in order to reallocate critical sensor tasks to other sensors.

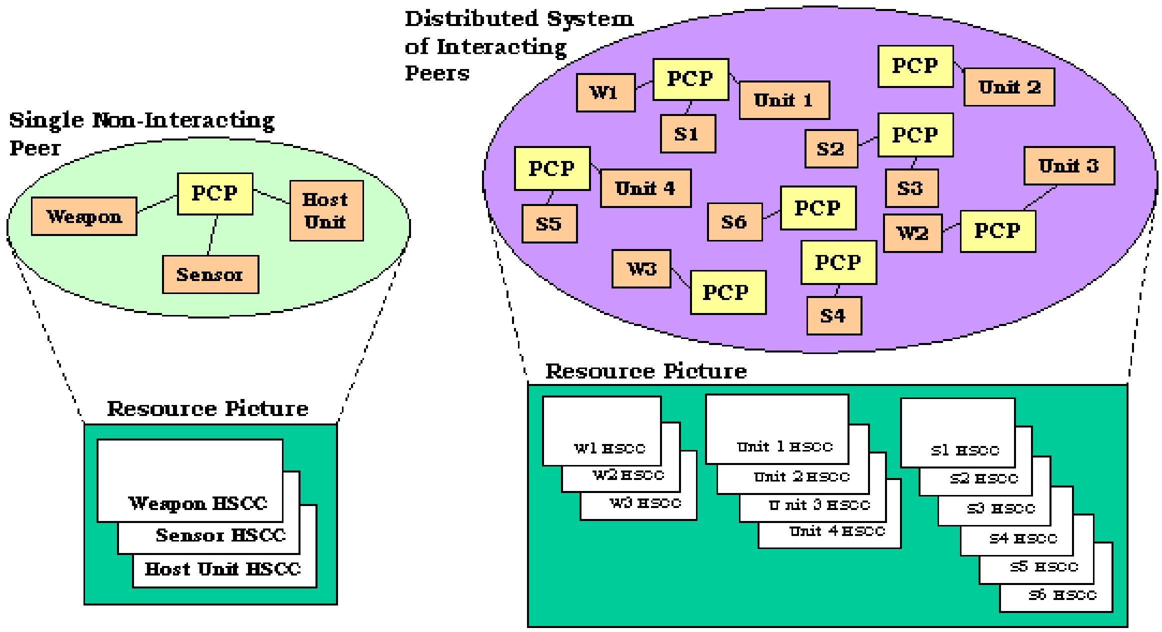


**Figure 14 – The Warfighting Resource Picture**

The basic concept for implementing DRM is the development of a set of processing algorithms, containing automated methods for optimization and decision aids, that will be replicated on each participating warfighting unit to effectively produce the same decision results given that each instantiation will be fed with the common information embedded in the SIAP. Figure 15 shows the major functions involved in DRM.

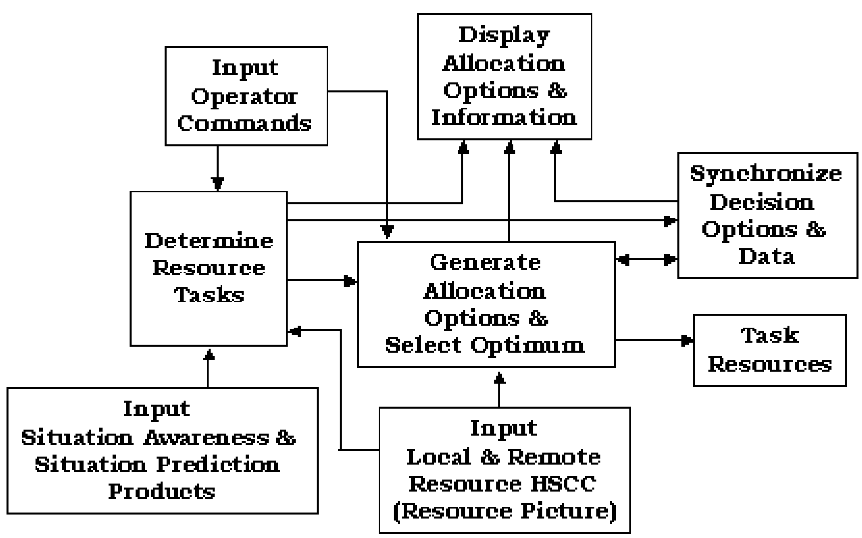


**Figure 15 – DRM Functionality**

The major DRM functions are the determination of resource tasks and the optimization engine that generate optimal task to resource allocations.  An additional capability that ensures commonality among peers is a synchronization process that shares allocation results to compare and correct for discrepancies.  This step may be necessary to ensure that distributed resources come to identical decision results when the commitment of distributed resources is critical for collaborative operations.

Sensor resource management forms the basis of level 4 data fusion defined by JDL (discussed earlier in the paper in Section 2.0).  Level 4 data fusion is process refinement or the feedback loop of tasking data sources or sensors in order to improve the air track picture in this application.  Thus, one of the major goals of distributed sensor management is to use all available sensors is the most optimal way to improve the SIAP and the overall situation awareness.  Improving data acquisition improves the ability to wargame, predict enemy COAs, and generate the most effective blue force COAs.

Another important aspect of managing sensor resources is the best use of them during engagements in support of weapon systems.  A major advancement in future aerospace warfare is the ability to use non-collocated sensors to support engagements—thus increasing detection areas, shortening the time necessary to make launch decisions, and improving engagement envelopes.  Using DRM, off-board sensors can be tasked to provide fire-control quality data to track targets; relay guidance to interceptors; and even illuminate targets during intercept endgame.  Using distributed sensor and weapon resources to support fire control is referred to as Integrated Fire Control (IFC) and is critical to advancing Joint C2 capabilities within the realm of aerospace warfare.

A major payoff of implementing these advanced PCP capabilities is the ability to select the optimal shooter or weapon system from the force to engage aerospace targets.  This very time-critical operation is best performed when each unit can make the determination simultaneously that a particular weapon system has the best shot opportunity.  An added layer of functional complexity is to also make the determination of which sensor or set of sensors from the distributed force are best suited to support the engagement.  DRM enables these capabilities.

An additional bonus feature of DRM is that it distributes command authority to individual units. Historically, the control of weapons and sensors has been the responsibility of the resident warfighter (Officer) in charge of the local unit (ship, aircraft, etc.).  Maintaining this control authority is part of the SIAP PCP concept for DRM.  Each peer would use the DRM capability to formulate sets of tasking for all relevant warfare assets (both resident and nonresident) in the battle group.   However, resident operators always have the ability to override resource taskings for local resources generated in an automated fashion by the DRM.  Thus, command authority is upheld.

**3.0 Conclusions**

The establishment of a NCW foundation through common processing and effective information sharing is the basis for future aerospace warfare advancement.  The advanced C2 concepts proposed in this paper are based on the SIAP philosophy of common processing at each peer and rely on automated data fusion and decision-making processes. Joint aerospace operations that will be enabled and/or enhanced based on the proposed concepts include:

- Advanced integrated fire control capabilities involving the optimized use of distributed warfare resources for collaborative engagement strategies.
- Selection of the best shooter and shot opportunities among weapon systems comprising a Joint force.
- Improved economy of weapon resources—optimal engagement strategies result in less weapon wastage.
- Improved SIAP accuracy and coverage (and therefore earlier detection and enhanced surveillance coverage) using feedback control tasking for optimized sensor data acquisition.
- Lifting the constraint of organic sensor/weapon pairing for engagements—enables improved engagement envelopes and more varied and flexible engagement strategies.
- Improved SIAP and CID results in improved airspace management and the possibility of achieving Joint engagement zones in which blue force fighter aircraft can perform missions in close proximity to interceptor engagements.
- Automated wargaming can provide Automated Battle Management Aids (ABMA) which enable dynamic replanning of tactical resources and collaborative planning capabilities.
- Enhanced situational awareness and wargaming can provide a state of information superiority, which supports enhanced decision-making by warfighters.

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