TECHNICAL REPORT 2003–029

Single Integrated Air Picture (SIAP) Attributes
Version 2.0

AUGUST 2003

SINGLE INTEGRATED AIR PICTURE (SIAP)
System Engineering
Task Force (SE TF)

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FOREWORD

Document Version Control

This document supercedes the June 2001 (Version 1.0) publication of *SIAP SE TF Technical Report 2001-001: Single Integrated Air Picture Attributes*.

This document is one in a series of four Technical Reports on the subject of SIAP Metrics, all of which are scheduled for regular, approximately annual updates. For most effective use, the most recent version of each document should be consulted. As of this writing (August 2003), the latest version and next scheduled update for the other three related technical reports are as follows:

SIAP SE TF Technical Report	Current Version (as of Aug 03)	Next Update
2001-002 SIAP MOEs and MOPs	October 2001	August 2003
2001-003 SIAP Metrics Implementation	October 2001	September 2003
2002-007 Ballistic Missile SIAP Metrics	November 2002	November 2003

FOREWORD

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The SIAP Attributes Technical Report is the result of collective efforts of members of the SIAP Attributes and Metrics Working Group, who drafted the content of the original report through several face-to-face meetings, teleconferences, and e-mail exchanges spanning the period from March to June, 2001, and revised the document to its present status between November 2002 and April 2003. The membership of the Working Group varied over this time period. The following individuals contributed to the report through their participation in either live or virtual meetings of the Working Group:

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EXECUTIVE SUMMARY

PROBLEM

The SIAP Implementation Plan states that the overarching objective of the SIAP SE TF is "to identify incremental improvements in the ... SIAP capability that will provide commensurate incremental improvements in warfighter capabilities" (SIAP Implementation Plan, 2001). Quantification of the SIAP capability in evaluative, predictive, and prescriptive terms is a necessary step towards assessment of such improvements. Multiple measures currently exist to evaluate the SIAP, but there is much overlap and some potential for conflict and confusion between similar measures. Furthermore, many of these existing measures have not been precisely quantified, or have been quantified with no apparent predictive or prescriptive goals in mind. Therefore, there is a clear need to consolidate and more rigorously define a core set of attributes, which provide the joint community with a common point of departure for quantifying and assessing a SIAP. These attributes must be traceable to Theater Air and Missile Defense (TAMD) and Combat Identification (CID) Capstone Requirements Document (CRD) Key Performance Parameters (KPPs), augmenting the latter where either quantitative precision or a sharper focus on warfighting benefit is necessary. The SIAP SE TF Technical Reports 2001-001, 2001-002, 2001-003, and 2002-007 were developed by the SIAP SE TF to correct for the deficiencies cited above by providing a standard set of definitions and algorithms for quantitative evaluation of air picture quality within the TAMD community. The measures apply to models, simulations, hardware and software in the loop experiments, operator in the loop exercises, and field exercises and evaluations. This revision is based on experience gained within the community from application of those technical reports across the spectrum of those venues.

OBJECTIVES

The goal is to establish a standard methodology for evaluation of the SIAP, based on a minimal but sufficient set of SIAP attributes. The attributes are to be accessible to measurement, and will be used to relate proposed engineering improvements to warfighting capability.

APPROACH AND SCOPE

Develop verbal definitions of SIAP attributes and mathematical definitions of supporting SIAP attribute measures that are derived from CRD requirements and associated KPPs. Identify and define any additional attributes required to comprehensively characterize the SIAP. The attributes and metrics in this report primarily address the SIAP KPPs for air breathing objects as defined in the TAMD CRD. SIAP SE TF Technical Report 2002-007 provides attributes and metrics for ballistic missile objects.

FINDINGS

The derivations and definitions of the enclosed SIAP attribute measures correspond to the TAMD and CID CRD KPPs. It is reasonable to assume that as SIAP system engineering expertise deepens, these definitions will also evolve to reflect that broadened expertise.

CONCLUSIONS

These attributes will form the basis for measuring SIAP-related qualities. The defined SIAP attributes will enable meaningful comparison of proposed engineering improvements and provide a universal reference frame for greater SIAP community awareness and communication.

RECOMMENDATIONS

The Draft TAMD CRD that is in the JROC approval cycle requires that the requirements set forth in the KPPs in that document be based on measurements set forth in the SIAP SE TF Technical Reports 2001-001, 2001-002, 2001-003, and 2002-007. The definitions of the air vehicle SIAP attributes as refined in this report should fully support these CRD-mandated measurements for the air vehicle component of the SIAP. Use these definitions to determine the impact of SIAP engineering improvements at the system/unit level on measurable warfighting capability at the Joint Forces Command level. Update this report on an annual basis, to reflect the further evolution of the SIAP SE's assessment methodology and lessons learned from actual use of the SIAP attributes.

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1. INTRODUCTION

This report establishes the standard methodology for evaluation of the quality of the air vehicle portion of the Single Integrated Air Picture (SIAP). Evaluations will be based on a set of SIAP attributes for which both qualitative definitions and mathematical formulations of a supporting set of measures are provided. These attributes and their associated quantitative measures are also needed to predict and prescribe SIAP improvements that translate into improved warfighting capability.

SIAP attributes measure the adequacy and fidelity of information which is used to form a shared understanding of the tactical situation (i.e., Situational Awareness (SA)), and to support battle management (BM) and engagement operations. As defined and quantified here, the attributes are meant to provide an approach to the challenge of linking system/unit level engineering performance to quantifiable warfighting capabilities.

The SIAP SE TF will use a collection of tools to define and develop a SIAP system engineering approach and methodology. Tools include models, simulations, hardware in the loop (HWIL) experiments, operator in the loop (OITL) experiments, and live exercises. These tools can be used to measure a wide variety of characteristics throughout a prescribed metrics hierarchy. Some tools provide a high fidelity assessment of system or subsystem performance as a function of engineering configuration. These tools expedite the determination of the root causes of SIAP deficiencies. A suite of potential tools will also be required to characterize and assess the warfighting benefit derived from a robust SIAP. A few tools, such as live exercises or evaluations (e.g., Roving Sands, Joint Combat Identification Evaluation Team exercises, etc.), span the entire metric range, and they can relate hardware configurations to specific warfighting capabilities. Typically there will be fewer opportunities to employ live exercises due to schedule and cost considerations. HWIL facilities offer the potential for repeatable measurements on existing systems at a lower cost. Models and simulations are especially useful when testing proposals for new systems or system changes, and can be activated at even lower costs. A particularly essential component of the SIAP SE's assessment strategy for the next few years will be the continuing development of the Joint Distributed Engineering Plant (JDEP) Technical Framework (SIAP IAP, 2003). The JDEP Technical Framework can be broadly defined as a capability to link distributed components in user-tailored federations which may span across HWIL, software-in-the-loop, and simulation venues (Dahmann, 2002). Simulations will in most cases need to be calibrated to live or HWIL results to provide confidence, and a mature JDEP Technical Framework may provide the means to ultimately migrate from HWIL to well-calibrated and cost-efficient simulation environments. No single tool is adequate to meet all the needs of the SIAP system engineering process. Therefore the tools will be used in conjunction with the SIAP attributes, the attributes being the means by which the results of one tool are transformed into another. For example, one model may be used to calculate the improvement in one or more SIAP attributes due to change in the correlation algorithm used by a particular system, and another model may be used to calculate the warfighting benefit from that level of SIAP improvement.

The Joint Requirements Oversight Council (JROC) has validated several Capstone Requirement Documents (CRDs) with particular relevance to the SIAP. Of these, the most pertinent are the Theater Air and Missile Defense (TAMD) CRD (2001), the Combat Identification (CID) CRD (2001), the Information Dissemination Management (IDM) CRD (2001), and the Global Information Grid (GIG) CRD (2001). These documents establish high-level performance requirements for Joint Forces in the form of Key Performance Parameters (KPPs) and related requirements. For each KPP relevant to the air vehicle component of the SIAP, for which either the TAMD or CID CRD sets a quantitative requirement, there is a corresponding SIAP attribute. The TAMD CRD also includes "Timeliness" as part of a SIAP KPP, with associated quantitative requirements to be determined. Because SIAP completeness, clarity, and accuracy (three of the SIAP attributes defined in this report) presuppose timely track data, a certain quality of timeliness is implied whenever appropriate goals are met with regard to the other attributes. For this reason, timeliness is not regarded here as a separate attribute. The issue is discussed in greater detail in Section 2.3.1.5 below, and will be readdressed whenever a revision to one of the aforementioned CRDs establishes a quantitative timeliness requirement.

The TAMD CRD prescribes SIAP support to three TAMD functional areas: SA, BM, and advanced engagement operations. The characteristics of the information required (as expressed in terms of attribute values) will vary with the functional areas supported, as may the information providers and users. The definitions and descriptions in this report are oriented toward the general SA and, to a lesser extent, the BM function. Assessment of advanced engagement operations may require some modification of the definitions described in this report. A more in-depth discussion of the three TAMD areas is included in the SIAP Integrated Assessment Plan (IAP) (2003).

The basic qualitative definitions of the SIAP attributes presented in Section 2.2 of this report are intended to be generally applicable to all SIAP tracks – broadly understood as conveying information on aerospace objects, ballistic and exoatmospheric objects included. However, the quantitative measures and supporting definitions addressed in this report are only intended to apply to tracks on unitary aerospace objects that do not split into multiple objects (as many types of ballistic missiles do). This limited scope covers the air vehicle component of the SIAP (that is, tracks on tactically significant airborne objects of interest). While many of the attributes defined in this report are expected to be applicable to ballistic missile defense (BMD) as well, issues specific to BMD require more detailed considerations, particularly with regard to reporting criteria, non-unitary missiles, and ballistic missile debris. Such considerations have been relegated to a separate report – SIAP SE TF Technical Report 2002-007: Ballistic Missile SIAP Metrics. That report presents a complete set of quantitative metrics applicable to the ballistic missile component of the SIAP.

The SIAP SE TF will employ a minimal set of attributes to characterize the shared information. There are eight SIAP attributes described in this report. The relationship of these eight Attributes to the TAMD and CID CRD KPPs is illustrated in Figure 1 below, and is explained more thoroughly in Appendix A. Italicized words in Figure 1 refer to KPPs and attributes that do not have direct correspondence.

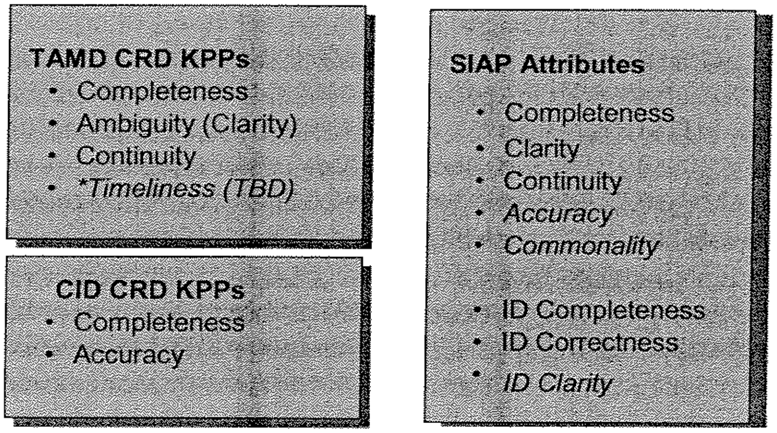

Figure 1. Relationship between SIAP attributes defined in this report and associated TAMD and CID CRD Key Performance Parameters

It should be noted that this table of correspondences applies to the SIAP attributes in relation to the *currently valid* (2001 publication) TAMD and CID CRDs. The correspondence is not quite complete, and even though this report and a CRD KPP may employ an attribute in the same qualitative sense, there may be some differences in the way the metrics are quantified. The SIAP SE TF is presently working with the services and other organizations responsible for proposing CRD revisions, with the goal of bringing the CRDs and this technical report into exact quantitative agreement on SIAP metrics with the next revision cycle (a revised TAMD CRD is in draft as of this writing).

The TAMD and CID CRDs set quantitative requirements in terms of threshold and objective values, which are expected to be refined as the analysis supporting them evolves. It is expected that the objective and threshold values of each attribute measure should ultimately depend on the operational context. A common operational context provides such vital considerations as environmental factors, the Red threat details, Blue force laydown, C2 hierarchy, rules of engagement, and other criteria. A collaboratively defined, Defense Planning Guidance (DPG)-based "Common Reference Scenario" (CRS) provides stressing scenarios and mission level vignettes for SIAP-related integrated system evaluation. The CRS forms the basis for developing the SIAP component of an integrated TAMD. SIAP attributes will be measured in context. That is, information has relevance to a user, with respect to a mission, in an operational context, with a defined architecture.

The objectives of this report, then, are to define and derive jointly agreed to SIAP attributes that flow from TAMD CRD and CID CRD KPPs, and to provide a vehicle to institutionalize the SIAP attributes.

1.1 The SIAP Metrics Hierarchy: General Definitions

The eight SIAP attributes defined in this report are quantifiable, testable, and measurable. They measure the quality of the shared information available to Joint and Combined Forces and are fundamental to assessing warfighting effectiveness. They do not, however, exhaust the full range of quantitative metrics which the SIAP SE will need to assess the warfighting effectiveness of specific proposed SIAP improvements. Figure 2 gives a sense of the role of the SIAP attributes as a "middle layer" in a SIAP metrics hierarchy, linking system/unit-level Measures of Performance (MOPs) to warfighting Measures of Effectiveness (MOEs). Examples of measures at each level are provided, and definitions of the levels follow.

- MOEs
  - Fratricide
  - Leakers
  - Weapon Expenditures
  - Others (TBD)
- Attributes
  - Completeness (2 Attributes)
  - Clarity (2 Attributes)
  - Continuity
  - Accuracy
  - Commonality
- MOPs
  - Correlation Performance
  - Data Exchange Latency
  - Navigation Errors
  - Sensor Uncertainty
  - Messages Received
  - Message Update Rate
  - Others (TBD)

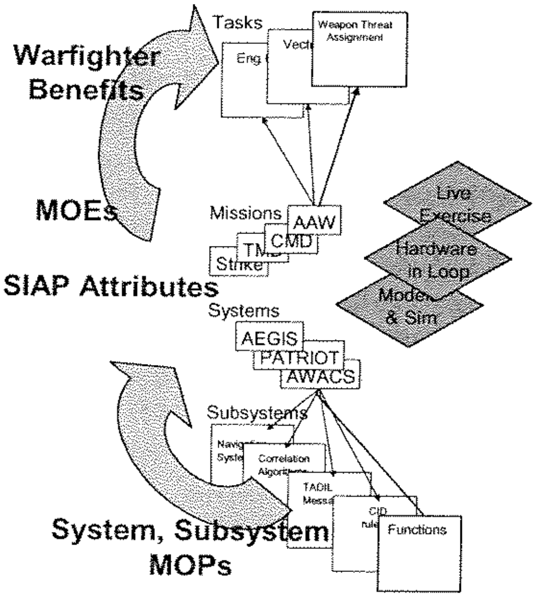

Figure 2. SIAP attributes and their role in the metrics hierarchy

For this report, MOEs, SIAP attributes, and MOPs will be defined as follows:

> MOE – measure of operational success that must be closely related to the objective of the mission or operation being evaluated. (DSMC Glossary, 2001)

A meaningful MOE must be quantifiable and a measure to what degree a mission objective is achieved.

> SIAP Attribute – a quantifiable property of a SIAP that is derived from TAMD and CID CRD requirements and associated KPPs.

> MOP – measure of a system's technical performance, for example, expressed as speed, payload, range, time on station, frequency, or other distinctly quantifiable performance feature. (DSMC Glossary, 2001)

MOEs, attributes, and MOPs together make up the SIAP metrics hierarchy. MOEs describe, in warfighting terms, the benefit of achieving a SIAP (note, however, that there may be motivations other than warfighting – for example, commercial air applications). Fratricide rate and weapons efficiency are examples of MOEs that are expected to improve with improved air picture quality. The SIAP attributes provide a standard means of characterizing the SIAP. As already discussed, the SIAP attributes derive from the TAMD and CID CRDs. The MOPs quantify aspects of system and subsystem performance that may be used in the analysis of SIAP shortfalls or the prescription of SIAP improvements. The ultimate goal of prescribing engineering performance improvements which result in significant warfighting benefit, translates analytically into identifying feasible changes in system-level MOPs that correlate, through a testing and modeling process, with meaningful improvements in MOEs. Because schedule and cost considerations will limit opportunities to use test venues that allow measurements across the entire hierarchy, most tools will use some degree of modeling and simulation and will make the linkage between MOPs and MOEs through the intermediate level of SIAP attributes.

Further discussion, and examples, of MOEs and MOPs can be found in SIAP SE TF Technical Report 2001-002. Definitions of the MOPs that will actually be used in connection with various SIAP SE-sponsored test events are being incorporated into updates of the SIAP Standard Data Management and Analysis Plan (2002, March draft) as the events are planned.

2. SIAP Attributes

2.1 Definition of Terms and Assumptions

The following terms are either used in the definitions of the SIAP attributes or are generally relevant to the discussion of SIAP assessments.

Common Reference Scenario (CRS) – a DPG-based operational context for SIAP assessments, providing a consistent baseline for evaluating current performance and proposed improvements.

Area of Influence (AOI) – "A geographical area wherein a commander is directly capable of influencing operations by maneuver or fire support systems normally under the commander's command or control" (JP 1-02, 2001). The definition of an AOI will be further refined in the CRS to bound the area within which SIAP attributes will be evaluated. The AOIs in the CRS may be broken down into limited participant/mission specific AOIs for the assessment of attributes for a given participant or mission.

Reporting Criteria – specify the objects that are to be included in the metric calculations and are derived from the TAMD CRD. A complete description will be prescribed in future updates to SIAP SE TF Technical Report 2001-003.

Object – for the air track portion of the SIAP, any cruise missile, fixed wing aircraft, rotary wing aircraft, air-to-surface missile, large caliber rocket, unmanned air vehicle, or other airborne object meeting air vehicle reporting criteria, in the area of influence. (The object set for the ballistic missile portion of the SIAP is addressed in Technical Report 2002-07.)

Track – "(1) the graphic and/or alphanumeric representation of an object, point, or bearing whose position and/or characteristics are collated from sensors and/or other data sources; (2) a collated set of data...associated with a track number for the purpose of representing the position and/or characteristics of a specific object, point, or bearing" (MIL-STD6011B, 1999). The attributes and metrics defined in this report are based on the definition of a track in the second sense.

Track Number – A number, applied to a located object, used to associate information and directives.

For purposes of metric calculations, the track set consists of actionable tracks where a track is considered actionable once it has an associated track number and is displayable to an operator. Metric calculations for two of the SIAP attributes – continuity and commonality – make explicit use of track numbers. These particular metrics must be understood in a network-specific sense, since the sharing of track numbers between participants may occur over several networks, each of which may have its own numbering scheme. The network chosen for assessment determines the type of track number to be used. For example, if continuity and commonality are to be based on Link-16, the appropriate number is the Link Track Number (LTN).

> <u>Pending Track</u> – "A track which has not been subjected to the identification process" (MIL-STD-6011B, 1999). Pending tracks are regarded as actionable, and therefore count towards the evaluation of all SIAP attributes.

> <u>Assigned Track</u> – in after-the-fact analysis of track data from an exercise or simulation, a track which meets a consistent condition for association with an object (addressed in the SIAP Metrics Implementation Technical Report, 2001-003). The assignment of tracks to objects may be time dependent.

A purpose of the SIAP is to achieve a correct and consistent understanding between participants within an AOI. A participant's understanding is based on information that can be displayed. For this reason SIAP attributes are based on data, held in the central track stores of the host system, that are displayable to the participant (see Figure 3, below). This data may come from local sensor measurements as well as remote sources such as Link-16, Link-11, or any other tactical data network.

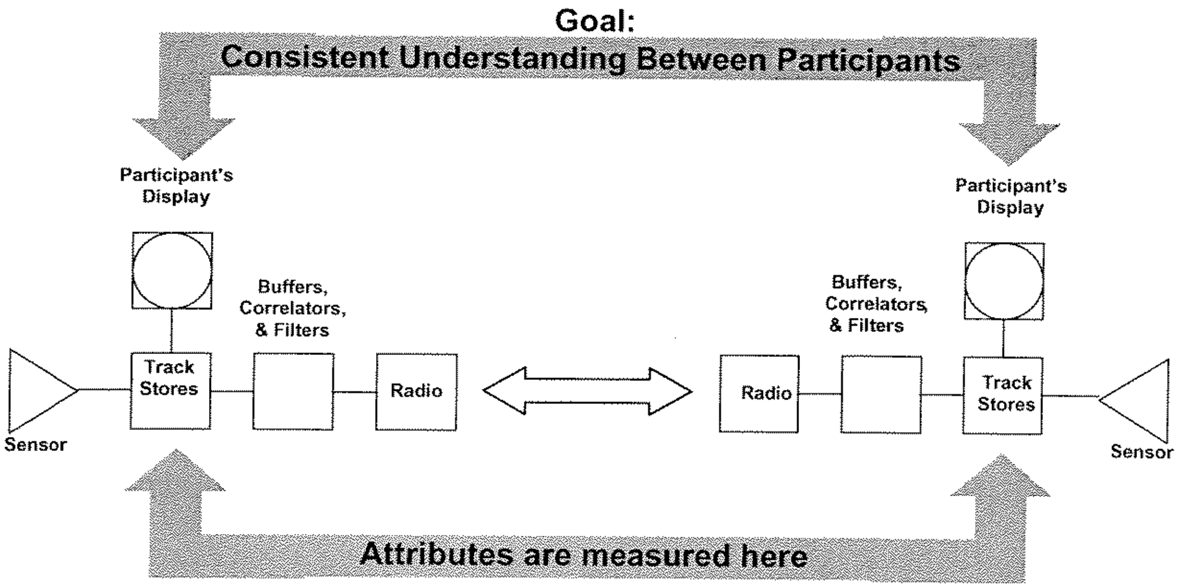

Figure 3. Measurement of SIAP attributes

This report focuses on the definitions of the SIAP attributes; issues involving their implementation will not be considered in detail, but will now be briefly summarized. There are a number of issues related to the determination of which tracks will be included in SIAP assessments. Tracks generated locally as well as those held through remote sources should be considered candidate tracks for scoring purposes, but the establishment of a definitive track base for current SIAP assessment requires a more thorough treatment than can be given here. There is a recognized need to discount certain "mutual" tracks so that repeated counting of essentially duplicate information does not bias the SIAP attributes. Other issues arise relating to the assignment of tracks to objects. An assignment procedure must be defined to ensure consistent scoring, and it may need to be automated for modeling and simulation purposes and for some experimental tests. However, it is beyond the scope of this report to recommend a specific assignment algorithm, prescribe a general procedure, or set procedural limits. There are other implementation issues specific to certain live exercises and established scoring methods. SIAP SE TF Technical Report 2001-003 discusses all of the above issues in detail.

2.2 Word Definitions of SIAP Attributes

The definitions of the attributes and associated measures are described below:

> Completeness: The measure of the portion of true air objects that are included in the SIAP. The air picture is complete when all objects are detected, tracked and reported.
>
> Clarity: The measure of the portion of the SIAP that contains ambiguous tracks and/or spurious tracks. The air picture is clear when it does not include ambiguous or spurious tracks.
>
> Continuity: The measure of how accurately the SIAP maintains track numbers over time. The air picture is continuous when the track number assigned to an object does not change.
>
> Kinematic Accuracy: The measure of how accurately the TAMD Family of Systems (FoS) reports track position and velocity. The air picture is kinematically accurate when the position and velocity of each assigned track agree with the position and velocity of the associated object.
>
> ID Completeness: The measure of the portion of tracked objects that are in an identified state. The ID is complete when all tracked objects are in an identified state.

ID Correctness: The measure of the portion of tracked objects that are in the correct ID state. The ID is correct when all tracked objects are in the correct ID state.

ID Clarity: The measure of the portion of tracked objects that are unambiguously identified. The ID is clear if no tracked object is in the ambiguous ID state.

Commonality: The measure of consistency of the air picture held by TAMD FoS participants. The air picture is common when the assigned tracks held by each participant have the same track number, position, and ID.

2.3 Complete Definitions of SIAP Attribute Measures

Complete definitions of the SIAP attribute measures are given in the following sections. Each attribute is given a precise mathematical formulation from which, in most cases, the following four levels of metrics can be derived:

Instantaneous system metric – the measure of the attribute at an instant in time from the perspective of a single participant. (Omitted in the case of Continuity, for which there is no meaningful instantaneous sense. Also omitted for Commonality which is an inherently multi-participant attribute.)

Time-averaged system metric – a time average, typically weighted according to an object or track count, of the instantaneous system metric. (Omitted in the case of Commonality, where it would coincide with the time-averaged IADS metric.)

Instantaneous IADS metric – an average over participants, typically weighted according to an object or track count, of the instantaneous system metric at a particular instant in time.

Time - averaged IADS ("roll-up") metric – a weighted average of an attribute over participants and time. For Continuity (which is not supported by an instantaneous system metric), the weighted average is over participants. For Commonality, the IADS metric is the time average of the consistency of the air picture across participants. The IADS metrics provide a high level assessment of the performance of the entire IADS.

It will be noted that the three levels of averaged metrics defined above are always derivable from the instantaneous system metric (when it is defined). The instantaneous system metric is in this sense an attribute's fundamental quantification, of which the various averages are simply higher-level variants.

In the definitions that follow, whenever all levels of metrics are applicable, explicit formulations of the instantaneous system metric, the time-averaged system metric, and the highest level average – the IADS or roll-up metric – are provided. The time-averaged system metric may be regarded as an intermediary between the fundamental instantaneous system attribute measure and the corresponding roll-up. Other intermediate averages, including the instantaneous IADS metric, can be extracted from the general mathematical procedure for averaging metrics, as outlined in Appendix B of this report. In the event that the SIAP attribute measures are being evaluated from Monte Carlo simulation results with multiple runs, the instantaneous system metric would itself normally be computed as an average over runs. As the treatment in Appendix B shows, run averages can also be incorporated into the general procedure, with essentially no alteration to the formalism.

Data supporting the SIAP attribute measures are assumed to be available over a particular time period of interest, which would normally be associated with the scenario (the CRS if the evaluation is following a scripted scenario). For the scoring of instantaneous metrics, the time period of interest is also assumed to be subdivided into a finite number of scoring subintervals. This division may be uniform over the period of interest, but could also be tailored to accommodate data availability or experimental design factors. Within each of these subintervals, a scoring time is selected according to a scheme pre-established by the user of the metrics. Some general recommendations for establishing scoring times and for aligning the data with the scoring times selected are provided in SIAP SE TF Technical Report 2001-003.

The metrics that are provided for each attribute below are in no way intended to limit the scope of any analysis (e.g., to measure the performance of systems, perform diagnostics, or find root causes of problems). The metrics that are specified here are meant to provide a set of measures that are consistently defined between analytic efforts and can be used to share and compare results. The attributes and their associated metrics are to be considered part of an evolutionary process.

The computation of the SIAP attributes requires some knowledge of truth regarding objects. In the absence of ground truth, such as in the case of an uninstrumented live exercise, it is still possible to obtain valuable estimates of most of these attributes by comparing the information available to one participant with that of another, or by examining the internal consistency of each individual participant's air picture over time.

The following notation is used throughout the mathematical definitions in this section:

Δt_k is the duration of the k^{th} time subinterval for scoring;
t_k is the k^{th} scoring time;

K is the total number of scoring times over the time period of interest for the scenario;
M is the total number of participants (or units to be scored) in the scenario;
J is the total number of objects ever occurring in the scenario.

In the case of a uniform division of the time period of interest into scoring subintervals, $\Delta t_k = (t_{end} - t_{start})/K$ = constant, where t_{start} and t_{end} are respectively the start and end times for evaluation, but in fact Δt_k can be eliminated from every equation in this section when it is constant. It need not be assumed that either the number of participants or the number of objects is constant over time. The constants M and J respectively are the total numbers of participants and objects that are *ever* of interest, and thus serve as upper bounds for the relevant numbers at any particular time. At the discretion of the experiment designer or user of the metrics, a participant may also be deemed "not of interest" at times when its data is unavailable due to experiment design limitations.

Other notation is defined as it is introduced in the presentation of formulae for the metrics. An index of all variables used will be provided in the 2003 update to SIAP SE TF Technical Report 2001-003, Appendix A.

2.3.1 TAMD CRD-Related Attributes

Attributes discussed in this section correspond to the SIAP KPPs described in the TAMD CRD. The method for calculation of the attribute measures is prescribed.

2.3.1.1 Completeness

The air picture is complete when all objects are detected, tracked and reported.

The instantaneous system completeness $C_m(t_k)$ at participant m at the k^{th} scoring time t_k is:

$$C_m(t_k) = \frac{JT_m(t_k)}{J_m(t_k)} 100\% \qquad (1)$$

where

$JT_m(t_k)$ = number of objects with at least one assigned track held by participant m at time t_k, and
$J_m(t_k)$ = number of objects at time t_k, assuming that participant m exists and is of interest for scoring at time t_k. If participant m either does not exist at time t_k or is not to be included in the scoring of the metric at time t_k, then both $JT_m(t_k)$ and $J_m(t_k)$ are set to zero by convention, and the instantaneous system completeness is not defined in this case. (This latter provision applies to any instantaneous, participant-specific quantity

entering into the definition of any SIAP attribute measure, but will not hereafter be explicitly noted.)

The time-averaged system level measure of the SIAP completeness C_m is an object-count weighted average across time:

$$C_m = \frac{\sum_{k=1}^{K} JT_m(t_k)\Delta t_k}{\sum_{k=1}^{K} J_m(t_k)\Delta t_k} 100\% \qquad (2)$$

This "object-count weighted" average gives more weight to the completeness during periods of time when the greatest number of objects are present in the AOI. Without such weighting, the attribute could be dominated by its value during long periods when there were very few objects. (Similar considerations apply to the remaining SIAP attribute measures.)

The roll-up measure of the SIAP completeness C is the following weighted average[1] of the time-averaged system level measure across participants:

$$C = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K} JT_m(t_k)\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} J_m(t_k)\Delta t_k} 100\%, \quad 0 \le C \le 100\%. \qquad (3)$$

The roll-up completeness attribute measure C can range in value from zero to 100%. The goal for Completeness is established by the Completeness KPP in the TAMD CRD. (See Appendix A for a discussion of the relationship between SIAP Attributes and the TAMD and CID CRDs).

2.3.1.2 Clarity

The air picture is clear when it does not include ambiguous or spurious tracks.

The quantification of the clarity attribute comprises two measures: one for ambiguous tracks and one for spurious tracks. Both ambiguous and spurious

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[1] While the sense in which the roll-up measure is a "weighted average" is somewhat abstract, the averaging formalism presented in Appendix B of this report shows how appropriate weights can be defined so as to allow interpretation of any of the roll-up metrics in this report as weighted averages – of either time-averaged system metrics or instantaneous IADS metrics.

tracks result in a loss of clarity, but the sources of the errors and the solution sets for the errors are different.

Ambiguous Tracks

Tracks are ambiguous when more than one track, assigned to the same object and not correlated within a system, are displayable to a participant.

The instantaneous system track picture ambiguity $A_m(t_k)$ at participant m at time t_k is:

$$A_m(t_k) = \frac{NA_m(t_k)}{JT_m(t_k)} \tag{4}$$

where $NA_m(t_k)$ = the number of assigned, uncorrelated tracks held by participant m at time t_k.

The time-averaged system level measure of ambiguity A_m is a tracked-object-count weighted average across time:

$$A_m = \frac{\sum_{k=1}^{K} NA_m(t_k)\Delta t_k}{\sum_{k=1}^{K} JT_m(t_k)\Delta t_k}. \tag{5}$$

The roll-up measure of overall ambiguity A is the following weighted average of the time-averaged system level measure across participants:

$$A = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K} NA_m(t_k)\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} JT_m(t_k)\Delta t_k}, \qquad A \geq 1. \tag{6}$$

The Ambiguity, A, can range from 1 to many tracks per object. The air picture may be said to be perfectly unambiguous when A is one. The goal for A is established by the TAMD CRD KPP for tracks per air object.

Spurious Tracks

A track is spurious when it is not assigned to any object.

The instantaneous system measure of the percentage of tracks that are spurious $S_m(t_k)$ as measured by participant m at time t_k is:

$$S_m(t_k) = \frac{N_m(t_k) - NA_m(t_k)}{N_m(t_k)} 100\% \qquad (7)$$

where $N_m(t_k)$ = the number of tracks held by participant m at time t_k.

The time-averaged system level measure of spurious tracks is a track-weighted average across time:

$$S_m = \frac{\sum_{k=1}^{K} [N_m(t_k) - NA_m(t_k)]\Delta t_k}{\sum_{k=1}^{K} N_m(t_k)\Delta t_k} 100\%. \qquad (8)$$

The roll-up measure of spurious tracks is the following weighted average of the time-averaged system level measure across participants.

$$S = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K} [N_m(t_k) - NA_m(t_k)]\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} N_m(t_k)\Delta t_k} 100\%, \qquad 0 \le S \le 100\%. \qquad (9)$$

In practice it may not always be possible to measure the fraction of spurious tracks in exercises because this attribute requires instrumented knowledge of all objects in the AOI. When collecting data in a live exercise with uncontrolled commercial air traffic, it is not always possible to determine if the tracks were generated by aircraft or were truly spurious. However, there may be features of the systems or characteristics of some tracks which may identify them as spurious.

The percentage of tracks that are spurious, S, ranges in value from 0% when perfect to 100%. The TAMD CRD provides a KPP for the percentage of tracks representing distinct objects. Thus the CRD requirement bounds the percentage of all tracks that are not spurious (100% - S).

Perfect clarity is attained when the air picture is perfectly unambiguous (A=1) and there are no spurious tracks (S=0).

2.3.1.3 Continuity

The air picture is continuous when the track number assigned to an object does not change.

The air picture at any given time is represented by a collection of track reports. Continuity is the measure of the persistence and consistency of these reports over time. The track number assigned to an object is the alphanumeric "tag" by which the track assigned to the object is identified (cf. MIL-STD-6011B, 1999). The amplifying data on the object with which a track is associated is a set of information unique to the track number. A loss or change of track number may entail loss or change of information on the object associated with the track report. The track number will change if the track is dropped and later picked up with a different track report, or if tracks are swapped between two objects that have been confused. The track number may also change when ambiguous tracks are resolved.

The SIAP attribute of continuity addresses only those aspects of information consistency which are directly associated with the track number. The more general notion of information continuity stretches across this attribute, the SIAP ID attributes (discussed below) and, in the case of information specific to particular tracks and objects, certain SIAP MOPs (cf. SIAP Technical Report 2001-002).

For SIAP assessments, the attribute of continuity is quantified in two ways. The first is the Rate of Track Number Changes and the other the Longest Track Segment.

The Rate of Track Number Changes on object j from the perspective of participant m is:

$$R_{j,m} = \frac{NU_{j,m} - 1}{TT_{j,m}} \tag{10}$$

where

$TT_{j,m}$ = total time object j is tracked by participant m,
$NU_{j,m}$ = the minimum number of track numbers assigned to object j which cover the period during which object j is tracked by participant m.
Mathematical definitions of the variables $TT_{j,m}$ and $NU_{j,m}$, further broken down in terms of track-to-truth assignment results, can be found in Appendix A of SIAP SE TF Technical Report 2001-003.

The concept embodied in this definition is somewhat more abstract than other properties represented by the SIAP attributes, and the visualization provided by Figures 4 and 5 may help to clarify the idea.

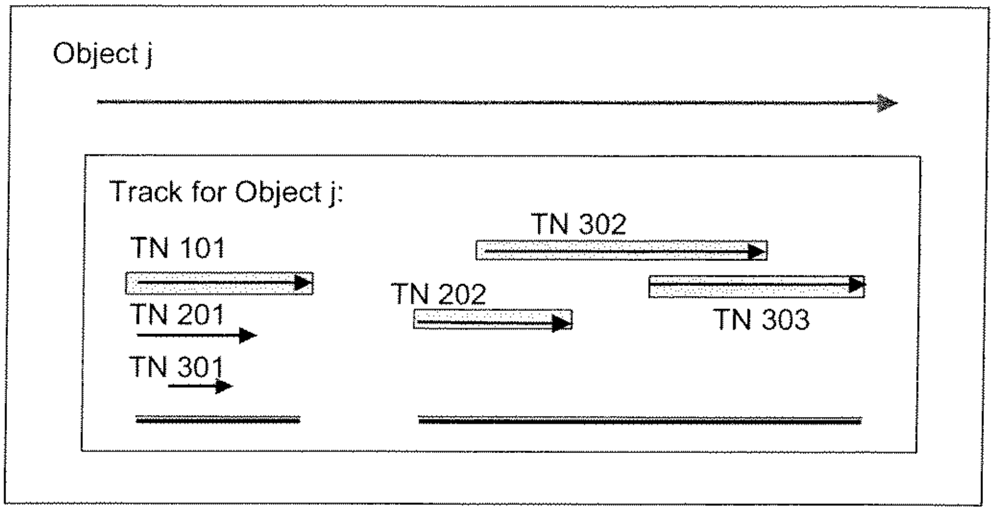

Figure 4. Example of determining Characteristic Track Lifetime

Time the object is tracked ($T_{T j,m}$) is the sum of the double (blue) lines. The minimum set of tracks that cover the period the object is tracked consists of: TN101, TN202, TN302, and TN303 (indicated by the boxed areas). The minimum number of tracks used to determine the rate of track number changes for this example is 4.

This definition is not affected by the problem posed by a track assignment algorithm where the assignment algorithm jumps back and forth between two possible track assignments (see Figure 5).

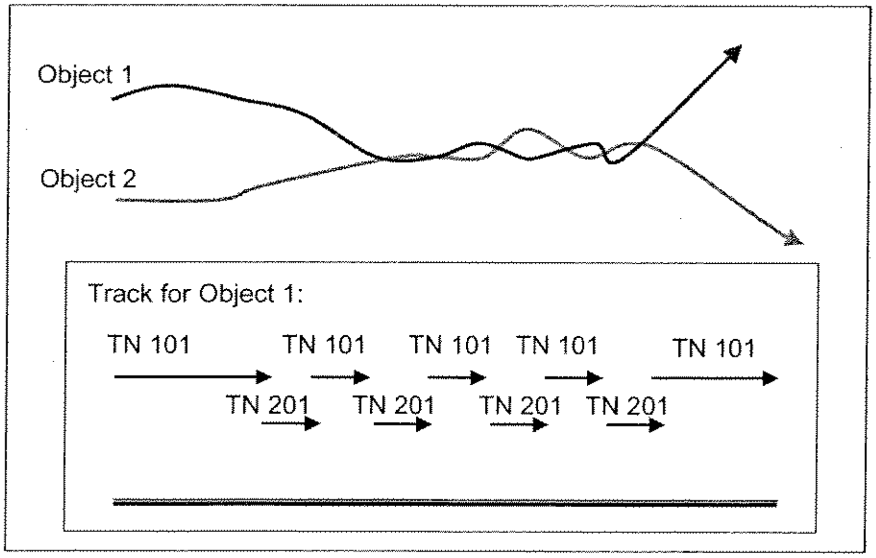

Figure 5. Multiple assignments of a track to two track numbers

In Figure 5, the double (blue) line represents the time the object is tracked. The tracks that cover the period when the object is tracked are TN 101 and TN 201. The minimum number of tracks for this example is 2. A different track assignment algorithm might have made different choices, but that will not affect the rate of track number changes. No matter how fast the track assignment algorithm swaps the assignment during the time the two objects are too close to distinguish accurately what is correct, the number of tracks assigned to the object will remain the same.

The system based Rate of Track Number Changes (for participant m) would be the object weighted average:

$$R_m = \frac{\sum_{j=1}^{J}(NU_{j,m} - 1)}{\sum_{j=1}^{J} TT_{j,m}} \quad . \qquad (11)$$

The IADS roll-up of the Rate of Track Number Changes is the following weighted average across participants:

$$R = \frac{\sum_{m=1}^{M}\sum_{j=i}^{J}(NU_{j,m} - 1)}{\sum_{m=1}^{M}\sum_{j=1}^{J} TT_{j,m}} . \qquad (12)$$

The Longest Track Segment is a measure of the longest time a track is assigned to an object, relative to the time the object is in the AOI. Expressed as a percentage of time, the Longest Track Segment LS_m at participant m is:

$$LS_m = \frac{\sum_{j=1}^{J} TL_{m,j}}{\sum_{j=1}^{J} T_j} 100\% \qquad (13)$$

where

$TL_{m,j}$ = time duration of the longest continuous single track segment with the same track number held by participant m assigned to object j,
T_j = total time of flight for object j, and
J = the number of objects over the evaluation period.

The roll-up measure of the Longest Track Segment LS is the following weighted average of the above over participants:

$$LS = \frac{\sum_{m=1}^{M}\sum_{j=1}^{J} TL_{m,j}}{\sum_{m=1}^{M}\sum_{j=1}^{J} T_j} 100\%, \qquad 0 \leq LS \leq 100\%. \qquad (14)$$

When LS equals 100 percent, all of the participants hold a stable, continuous track file on each object. This does not preclude spurious or redundant tracks, and these, if they do occur, need not be continuous. If Completeness (C) is not 100 percent (so that there are untracked objects), then LS cannot take a value larger than C.

In the limit of perfect Continuity, the Longest Track Segment (LS) approaches the value of Completeness (C), and the rate of track number changes approaches zero.

2.3.1.4 Kinematic Accuracy

The air picture is kinematically accurate when the position and velocity of each assigned track agree with the position and velocity of the associated object.

Different tasks have different requirements for SIAP accuracy. For general background objects for which participants have a low level of interest and no engagements are underway, the objective is to maintain SA. For the purpose of SA, the track accuracy needs to be good enough for correlation with local tracks so that they are not dualed or misidentified.

Once an engagement has been ordered, the engagement target and all other objects in the vicinity will require special attention. Track accuracy requirements increase in order to support the engagement, maintain SA, cue fire control radar, vector fighters, and guide missiles in flight. A different level of track accuracy is required by the engaging units. When engaging units are integrated for the purpose of fire control, such that one unit fires on the basis of another's sensor data, the highest level of track accuracy is required. In general the kinematic accuracy of the track is going to depend on the activity and the special needs of the participant.

For the purpose of assessing the adequacy of the SIAP to support these different levels of activity, a measure of the absolute track accuracy is needed. A mathematical definition of the position and velocity accuracy, $PA_{j,m}(t_k)$ and $VA_{j,m}(t_k)$, for object j tracked by participant m at time t_k, is provided by separately taking root mean square (RMS) averages of the track position and velocity errors over all tracks assigned (to that object, at that time for that participant):

$$PA_{j,m}(t)=\sqrt{\frac{\sum\limits_{n\in D_{j,m}(t_k)} X_{j,n,m}(t_k)^2+Y_{j,n,m}(t_k)^2+wZ_{j,n,m}(t_k)^2}{NA_{j,m}(t_k)}} \tag{15}$$

$$VA_{j,m}(t)=\sqrt{\frac{\sum\limits_{n\in D_{j,m}(t_k)} VX_{j,n,m}(t_k)^2+VY_{j,n,m}(t_k)^2+wVZ_{j,n,m}(t_k)^2}{NA_{j,m}(t_k)}} \tag{16}$$

where

$X_{j,n,m}(t_k)$, $Y_{j,n,m}(t_k)$, $Z_{j,n,m}(t_k)$ are the Cartesian position coordinates for object j in the local east-north-up coordinate frame of track n held by participant m (track-centered coordinate frame) at time t_k,

$VX_{j,n,m}(t_k)$, $VY_{j,n,m}(t_k)$, $VZ_{j,n,m}(t_k)$ are the velocity components of object j in the local east-north-up coordinate frame of track n held by participant m (track-centered coordinate frame) at time t_k,

$D_{j,m}(t_k)$ is the set of tracks held by participant m and assigned to object j at time t_k,

$NA_{j,m}(t)$ is the cardinality of $D_{j,m}(t_k)$, that is, the number of tracks held by participant m that are assigned to object j at time t_k, and

w is a weighting used to reduce the significance of the vertical position and velocity errors on 2-D sensors. Currently all SIAP assessments are using constant weight values of either one or zero over all participants considered in the assessment, but special considerations for complex architectures with mixes of 2-D and 3-D sensors may be explored in the future.

The instantaneous system level measures of position and velocity accuracy, $PA_m(t_k)$ and $VA_m(t_k)$, are respectively the RMS averaged position and velocity errors over all assigned tracks held by participant m at time t_k:

$$PA_m(t_k)=\sqrt{\frac{\sum\limits_{j=1}^{J} NA_{j,m}(t_k)PA_{j.m}(t_k)^2}{\sum\limits_{j=1}^{J} NA_{j,m}(t_k)}}\ , \tag{17}$$

$$VA_m(t_k)=\sqrt{\frac{\sum\limits_{j=1}^{J} NA_{j,m}(t_k)VA_{j,m}(t_k)^2}{\sum\limits_{j=1}^{J} NA_{j,m}(t_k)}}\ . \tag{18}$$

Note that weighting the sums over objects by $NA_{j,m}(t)$ has the same effect as taking an unweighted average over assigned tracks (see Appendix B).

The time-averaged system level measures of position and velocity accuracy, PA_m and VA_m, are the analogous RMS averages across assigned tracks and scoring times:

$$PA_m = \sqrt{\frac{\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k) PA_{j,m}(t_k)^2 \Delta t_k}{\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k)\Delta t_k}} \qquad (19)$$

$$VA_m = \sqrt{\frac{\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k) VA_{j,m}(t_k)^2 \Delta t_k}{\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k)\Delta t_k}}. \qquad (20)$$

Finally, the roll-up measures are the analogously weighted averages across participants of the time-averaged system metrics:

$$PA = \sqrt{\frac{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k) PA_{j,m}(t_k)^2 \Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k)\Delta t_k}}, \quad PA \geq 0, \qquad (21)$$

$$VA = \sqrt{\frac{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k) VA_{j,m}(t_k)^2 \Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{J} NA_{j,m}(t_k)\Delta t_k}}, \quad VA \geq 0. \qquad (22)$$

In general, the requirement for accuracy depends on the needs of the user. Although the kinematic accuracy provides a necessary diagnostic, any requirement for accuracy depends on the mission. For the mission of achieving and maintaining a consistent and coherent air picture, the accuracy must be sufficient to permit the correct correlation of the network track with the local track and avoid miscorrelation of local tracks with the wrong network track. Kinematic accuracy is therefore a contributing factor in the SIAP attributes of Clarity and Continuity. In addition, kinematic accuracy is the central factor in determining whether or not closely spaced objects (relative to the resolution of the sensors) may swap track numbers and CIDs from one to the other.

The TAMD CRD (2001) does not provide a single KPP requirement for Accuracy although it does attempt to establish a limit to the error introduced in the position of a track due to latency in the network. This is, of course, just one part of the overall contribution to the kinematic accuracy – other factors include failure to achieve time synchronization, poor data registration and gridlock, deficiencies in processing by tracking or correlation algorithms, to name a few. The Draft TAMD CRD that is currently in the JROC review cycle does specifies track accuracy requirements for both position and velocity, which correspond to the SIAP attribute measures of Position Accuracy and Velocity Accuracy.

2.3.1.5 Discussion on Timeliness

"Timeliness" is mentioned as a required SIAP attribute in the TAMD CRD. However, the CRD offers neither a general definition of SIAP timeliness nor a standard for the timeliness of track data. For each top-level Information Exchange Requirement (IER) in the CRD, including for track data, timeliness is "to be determined."

Although there will be no explicit determination of "timeliness" *per se* at the level of SIAP attributes, the SIAP SE TF recognizes the importance of the timeliness requirement, and will recommend the use of various measures of performance (MOPs) to capture the effects of network time delays in root cause analysis. A typical MOP might be the elapsed time between the availability of certain information for distribution on a network and the time that the information is available to a participant who needs it. Examples of effects (expected to be second-order) on quantified SIAP attributes would be: the degradation of completeness due to undistributed information during the elapsed time period, the degradation of clarity from dualing and local/remote miscorrelation (which can be exacerbated by unaccounted-for time lags), dropped tracks (reflected by a decline in continuity), decay in accuracy over time (e.g., latency issues associated with IFC accuracy requirements), and non-commonality due to non-uniform distribution of data.

Timeliness enters into higher-level warfighting benefits assessments as well, and other metrics would arise from analysis of any of the instantaneous attribute measures in conjunction with the decision-making or engagement timeline for a particular mission (e.g., does a decision-maker or engaging unit have the quality of information needed by the time the decision must be made or the engagement executed?). The SIAP SE TF will address this aspect of timeliness through measures of effectiveness (MOEs) at the mission, force and campaign levels of the metrics hierarchy.

With regard to CID timeliness, the CID CRD does specify a standard KPP for the timeliness of CID data.

"The CID process must be accomplished:
a. Soon enough to provide military options including warning and engagement decisions.
b. Without increasing the engagement time for any weapon system more than XX seconds."

The SIAP SE TF has not assigned a SIAP attribute that corresponds to this KPP. However, as already suggested, the assessment of warfighting benefits will proceed within the context of specific missions, for which MOEs will be introduced to cover this KPP.

2.3.2 CID CRD-Related Attributes

The CID attributes are completeness, correctness, and clarity. The CID attributes of completeness and correctness address the KPPs in the CID CRD. The clarity attribute is introduced to provide an explicit measure of ID consistency across the TAMD FoS in the case where there are multiple tracks on an object.

The CID attributes are assessed separately for the sets of: friendly (Blue) truth objects, hostile (Red) truth objects, and neutral or other truth objects if applicable. An additional measure is computed over objects of all allegiance classes. Each CID attribute thus yields a separate score for each of the three force allegiance classes, plus an overall value. The CID attributes are based on the classification of a participant's instantaneous track data on a particular tracked object into one of four different ID states:

- Correct
- Not Identifed
- Incorrect
- Ambiguous

The ID state of an object is correct if at least one associated track is identified correctly and no associated tracks are identified incorrectly. The ID state of an object is incorrect if at least one associated track is identified incorrectly and no associated tracks are identified correctly. An object's ID state is ambiguous if at least one associated track is identified correctly and at least one associated track is identified incorrectly. The ID state of an object is not identified if all associated tracks are either unknown or pending. Since these four states are mutually exclusive, exhaustive, and account for all tracked objects, the fractions of tracked objects falling into each of the four states sum to unity. Three independent measures are thus defined. The attributes of ID completeness, correctness, and clarity, presented below, correspond to one possible way of selecting three independent measures.

Table 1 describes an example set of rules for assessing the correctness of a CID label on an object. The ID taxonomy (first column of Table 1) is taken from MIL-STD-2525B (1999). For objects of each force allegiance type (Friend, Hostile or Neutral), the table provides a possible definition of "Correct," "Incorrect," and "Not Identified." The definition used depends upon the scenario and judgement of the Force Commander. The CRS used by the SIAP SE TF will include a definition of correct, incorrect, unknown, and ambiguous. By no means are the assignments shown in Table 1 intended to limit CID designations to the given set; in particular, this is not meant to imply that ID "correctness" should necessarily be limited to force allegiance considerations. The sample assignments are simply given, in lieu of a complete scenario description, to help illustrate the attributes associated with CID in the discussion to follow.

Table 1
Example Set of CID Designations

	ID of Truth Object		
ID of Track	Friend	Hostile	Neutral
Pending	N	N	N
Unknown	N	N	N
Assumed Friend	C	I	I
Friend	C	I	I
Neutral	I	I	C
Suspect	I	C	I
Hostile	I	C	I

C = Correct N = Not Identified I = Incorrect

The next three attributes are specifically associated with the CID CRD KPPs. These are ID completeness, ID correctness, and ID clarity.

2.3.2.1 ID Completeness

The ID is complete when all tracked objects are in an identified state (i.e., a state other than "not identified").

The instantaneous system ID completeness can be represented by the percentage of objects $C_{IDX_m}(t_k)$ of allegiance type X at participant m at time t_k that are complete:

$$C_{IDX_m}(t_k) = \left(\frac{JTX_m(t_k) - JUX_m(t_k)}{JTX_m(t_k)} \right) 100\% \qquad (23)$$

where

$JTX_m(t_k)$ = the number of tracked objects of allegiance type X tracked by participant m at time t_k, the type variable X taking the possible values B (Blue), R (Red) or N (Neutral),
$JUX_m(t_k)$ = the number of tracked objects of allegiance type X in the "not identified" ID state held by participant m at time t_k. (This includes any specific ID assignments, or combinations thereof, that are defined to be "not identified" assessments in the CRS.)

The corresponding overall measure of ID completeness $C_{ID_m}(t_k)$ may be computed from the three allegiance type-specific measures and the tracked object counts, as follows:

$$C_{ID_m}(t_k) = \frac{JTB_m(t_k)C_{IDB_m}(t_k) + JTR_m(t_k)C_{IDR_m}(t_k) + JTN_m(t_k)C_{IDN_m}(t_k)}{JT_m(t_k)}, \qquad (24)$$

or equivalently, equation 23 may be applied with the 'X's omitted and with no consideration of force allegiance in the variable definitions.

The time-averaged system level measures of the CID completeness C_{IDX_m} are the object-weighted averages of the instantaneous measures over time:

$$C_{IDX_m} = \frac{\sum_{k=1}^{K} [JTX_m(t_k) - JUX_m(t_k)]\Delta t_k}{\sum_{k=1}^{K} JTX_m(t_k)\Delta t_k} 100\%, \qquad (25)$$

where the 'X' is omitted if the overall measure is being computed.

The roll-up measure C_{IDX} is the analogously weighted average across participants:

$$C_{IDX} = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K}[JTX_m(t_k) - JUX_m(t_k)]\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} JTX_m(t_k)\Delta t_k} 100\%, \quad 0 \le C_{IDX} \le 100\%, \quad (26)$$

where again, the 'X' is omitted if the overall ID completeness roll-up CID is to be computed (this stipulation applies to the overall measures for the remaining CID attributes as well, but will not be explicitly noted hereafter.)

The fraction of ID completeness ranges from zero to 100%. The CID CRD establishes a requirement for the completeness (CID Probability of ID KPP) of the CID information broken down by object force allegiance – hostile, friend, and neutral. Hence the completeness goals in the CRD equate to thresholds and objectives for the attribute measures CIDR, CIDB, and CIDN.

2.3.2.2 ID Correctness

The ID is correct when all tracked objects are in the correct ID state.

The instantaneous system ID correctness can be represented by the percentage of objects $IDCX_m(t_k)$ of allegiance type X labeled correctly at a participant m at time t_k:

$$IDCX_m(t_k) = \frac{JCX_m(t_k)}{JTX_m(t_k)} 100\% \qquad (27)$$

where

$JCX_m(t_k)$ = number of tracked objects of allegiance type X in the correct ID state (as defined in the CRS) held by participant m at time t_k.

The corresponding overall measure of ID correctness $ID_{C_m}(t_k)$ may be computed from the three allegiance type-specific measures and the tracked object counts, as follows:

$$ID_{C_m}(t_k) = \frac{JTB_m(t_k) ID_{CB_m}(t_k) + JTR_m(t_k) ID_{CR_m}(t_k) + JTN_m(t_k) ID_{CN_m}(t_k)}{JT_m(t_k)}, \qquad (28)$$

or equivalently, equation 27 may be applied with the 'X's omitted and with no consideration of force allegiance in the variable definitions.

The time-averaged system measure of the ID correctness $IDCX_m$ is the object-weighted average of the above over time:

$$\mathrm{IDCX}_m = \frac{\sum_{k=1}^{K} \mathrm{JCX}_m(t_k)\Delta t_k}{\sum_{k=1}^{K} \mathrm{JTX}_m(t_k)\Delta t_k} 100\%. \qquad (29)$$

The roll-up measure IDCX is the analogously weighted average of this across participants:

$$\mathrm{IDCX} = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K} \mathrm{JCX}_m(t_k)\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} \mathrm{JTX}_m(t_k)\Delta t_k} 100\%, \quad 0 \le \mathrm{IDCX} \le 100\%. \qquad (30)$$

The range of possible values for ID correctness is from zero to 100%. The CID CRD establishes a KPP requirement on the conditional probability of correct identification of an object given that the object is "characterized by CID systems" (CID CRD, 2001). Interpreting "characterized" as "in a state other than 'Not Identified'" (an interpretation consistent with the KPP language and accompanying examples in the CID CRD), this translates to a requirement on the ratio of overall ID correctness to overall ID completeness, IDC/CID.

2.3.2.3 ID Clarity

The ID is clear if no tracked object is in the ambiguous ID state.

The instantaneous system ambiguity $\mathrm{IDAX}_m(t_k)$ of the CID for objects of allegiance type X at participant m at time t_k is given by:

$$\mathrm{IDAX}_m(t_k) = \frac{\mathrm{JAX}_m(t_k)}{\mathrm{JTX}_m(t_k)} 100\% \qquad (31)$$

where
$\mathrm{JAX}_m(t_k)$ = number of tracked objects of allegiance type X in the ambiguous ID state held by participant m at time t_k.

The corresponding overall measure of ID ambiguity $\mathrm{ID}_{A_m}(t_k)$ may be computed from the three allegiance type-specific measures and the tracked object counts, as follows:

$$\mathrm{ID}_{A_m}(t_k) = \frac{\mathrm{JTB}_m(t_k)\mathrm{ID}_{AB_m}(t_k) + \mathrm{JTR}_m(t_k)\mathrm{ID}_{AR_m}(t_k) + \mathrm{JTN}_m(t_k)\mathrm{ID}_{AN_m}(t_k)}{\mathrm{JT}_m(t_k)}, \qquad (32)$$

or equivalently, equation 31 may be applied with the 'X's omitted and with no consideration of force allegiance in the variable definitions.

The time-averaged system level measure of CID ambiguity IDAX_m is the object-weighted average of the above over time:

$$\mathrm{IDAX}_m = \frac{\sum_{k=1}^{K} \mathrm{JAX}_m(t_k)\Delta t_k}{\sum_{k=1}^{K} \mathrm{JTX}_m(t_k)\Delta t_k} 100\%. \qquad (33)$$

The roll-up measure IDAX is the analogously weighted average of this across participants:

$$\mathrm{IDAX} = \frac{\sum_{m=1}^{M}\sum_{k=1}^{K} \mathrm{JAX}_m(t_k)\Delta t_k}{\sum_{m=1}^{M}\sum_{k=1}^{K} \mathrm{JTX}_m(t_k)\Delta t_k} 100\%, \quad 0 \le \mathrm{IDAX} \le 100\%. \quad (34)$$

The possible range of values for ID ambiguity is from zero to 100%. As already noted, there is no CID CRD KPP currently associated with this attribute. Clearly the objective of the SIAP is to keep the ambiguity as close to zero as possible.

Because the fractions corresponding to the four ID states sum to unity, an attribute defining ID Incorrectness is redundant.

2.3.3 Combination Attribute

According to the TAMD CRD (2001), "The SIAP consists of common, continuous, and unambiguous tracks of airborne objects of interest in the surveillance area." "Common" in this context is generally understood to involve a consistent understanding among all participants. While it is not intended that all network participants must receive all data, it is desired that any information needed by a participant or a group of participants be available to them. Therefore if a group of participants have a need for the same information, it should be held by all of them. Information needed for SA is broadly needed by all network participants; thus, generally speaking, the SA picture should be consistent among all participants.

2.3.3.1 Commonality

The air picture is common when the assigned tracks held by each participant have the same track number, position, and ID.

The instantaneous commonality $\mathrm{CM}(t_k)$ is computed as follows:

$$\mathrm{CM}(t_k) = \frac{\mathrm{NC}(t_k)}{\mathrm{NS}(t_k)} 100\% \qquad (35)$$

where

$\mathrm{NC}(t_k)$ = the number of assigned tracks held by all participants at time t_k, such that:
-each track is represented by a unique track number, common to all participants
-position and time data on each track is the same for all participants, to within specified tolerances (defaults are currently ± 5 min in latitude and longitude, ± 20 kft in altitude)
-associated ID data on each track is the same for all participants
and
$\mathrm{NS}(t_k)$ = the number of assigned tracks held by at least one participant at time t_k.

The roll-up measure CM is obtained by track-weighted averaging over time:

$$\mathrm{CM} = \frac{\sum_{k=1}^{K} \mathrm{NC}(t_k)\Delta t_k}{\sum_{k=1}^{K} \mathrm{NS}(t_k)\Delta t_k} 100\%, \quad 0 \le \mathrm{CM} \le 100\%. \qquad (36)$$

The computation of the roll-up of commonality finds the track information that is held simultaneously by all participants. As the number of participants goes up, the commonality of the network participants will typically go down. For some diagnostic purposes it may be useful to compute the commonality on a pair-wise basis. That is, compare the track stores of each participant with every other participant. This calculation will determine if any lack of commonality seen in the roll-up is attributable to a particular participant or if it was a generalized deficiency. An alternative to the roll-up in equation 36 would be the average over all participants of the pair-wise commonality of each participant with all possible partners. This definition may be found to be useful, and if so, the definition of commonality could evolve.

2.3.4 Formation Tracking Considerations

As noted in the Introduction to this report, the definitions and formulae of Sections 2.1 through 2.3.3.1 are framed to support published SIAP and CID requirements – specifically those expressed in the KPP language of the TAMD CRD (2001) and the CID CRD (2001). These 2001 documents make no explicit reference to the use of *formation tracks*. A formation track is a track intentionally representing two or more objects, the number of objects being designated by an amplifying data element known as the *track strength*. Since requirements in the TAMD CRD (2001) take no account of formation tracks, the SIAP KPP has in the past been interpreted as imposing a strict "one track per object" condition on the SIAP, without regard for any use of formation tracking or the track strength field (CINCUSJFCOM J8 Memorandum, 21 June 2001).

However, the SIAP SE, JTAMDO, USJFCOM, and other parties to the current TAMD CRD revision process are now advocating a revision to the SIAP requirements that would explicitly acknowledge the use of formation tracking as a means to attain a SIAP (TAMD CRD, March 2003 draft). (Indeed, the proposed language would *require* the use of formation tracks in certain circumstances, though this requirement would not be part of the SIAP KPP.) The revised TAMD CRD has not yet been validated by the JROC, but there is no reason to suppose that the JROC would reject the amended SIAP requirements.

It is the intent of the SIAP SE to adapt the attributes defined in this report to accommodate the use of formation tracks in accordance with the next published revision of the TAMD CRD. For some of the SIAP attribute measures, this will be fairly straightforward, at least when the track strength is reported as a number. For instance, if it is assumed that every track of strength n is eligible for assignment to up to n truth objects at a given time, the Completeness measure (Section 2.3.1.1) can be computed by equation 1 with the variable $JT_m(t_k)$ interpreted as the number of objects covered by these (possibly one-to-many) assignments (at participant m, time t_k). The Clarity measures (Section 2.3.1.2) can be similarly adjusted by reinterpreting the variables $NA_m(t_k)$ and $N_m(t_k)$ as, respectively, the sum of the strengths of assigned tracks and the sum of the strengths of all tracks (held by participant m at time t_k). However, the details of this one-to-many assignment procedure have yet to be worked out in a form suitable for automated implementation. Furthermore, there are more subtle effects on some of the other of the other SIAP attributes (continuity and accuracy, for example) which have not been addressed. A complete schema for accommodating formation tracks within the SIAP assessment methodology will therefore be deferred to the 2004 revisions of SIAP SE Technical Reports 2001-001 and 2001-003.

3. CONCLUSIONS AND RECOMMENDATIONS

Meaningful and precise definitions and derivations of SIAP attributes have been presented, based upon the guidelines found in the TAMD and CID CRDs. These definitions are quantifiable, testable and measurable. Having defined these attributes, the SIAP SE TF will use them as part of a system engineering process to successfully evaluate, predict, and prescribe meaningful engineering recommendations for a SIAP. With universal SIAP attribute definitions effectively vetted through the services and applicable agencies, the joint community will have a common reference for defining SIAP-related warfighting capability.

Analysis will be conducted using more than one vignette and more than one scenario to ensure a wide variety of tactical circumstances. This will help eliminate scenario dependencies and permit more comprehensive analysis. A high-level description of scenarios currently under consideration is provided in SIAP SE TF Technical Report 2002-003. The details of these campaigns are to be provided in other documents, for reasons of classification.

The companion report SIAP SE TF Technical Report 2001-002 outlines the plan for incorporation of the SIAP attributes into an overall hierarchy of SIAP metrics, including MOPs and MOEs. Various SIAP SE-sponsored analysis efforts (some underway, others still in planning) are aimed at providing quantitative traceability among selected metrics at different levels in this hierarchy (see Figure 6). The companion report SIAP SE TF Technical Report 2001-003 provides procedures for implementing evaluation of SIAP attribute measures in an automated data collection and processing environment. The SIAP SE TF plans to publish updates to all three of these documents approximately annually. While additional refinement to the definitions of metrics is still needed at the MOP level, and the automated implementation plan is expected to further evolve, the definitions and supporting mathematics specific to the SIAP attributes as presented in this report are expected to remain relatively constant over time.

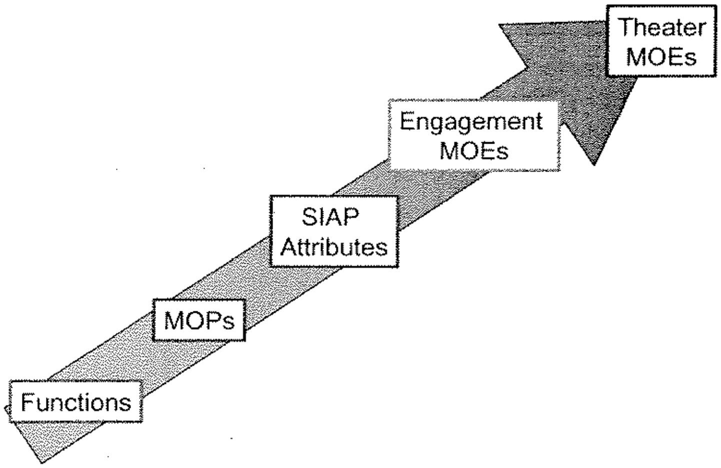

Figure 6. SIAP attributes within the traceability process

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APPENDIX A.

Correspondence of TAMD and CID CRD Requirements to SIAP Attributes

The JROC has already established some standards for assessing a SIAP in the form of Key Performance Parameters (KPPs) in the TAMD and CID CRDs. It is taken as a given that these must be reflected within the final set of SIAP Attributes. In defining the SIAP Attributes, the SIAP SE TF has found it necessary to augment the KPPs slightly to arrive at a complete description of all aspects of the SIAP believed to be both independent and significant for analysis purposes. In addition, since the CRD KPPs are oriented towards requirements rather than analysis, the SIAP SE TF has provided rigorous and explicit definitions with analytical utility in mind, and intends to provide specific guidelines for implementation of the definitions.

Tables A-1 and A-2 below show the correspondence between the attributes for which the CRD established goals and the attributes that will be used by the SIAP SE TF. As already noted in the Introduction to this report, these correspondences refer to the *currently valid* (2001 publication) CRDs. The correspondences will be much closer with the next revisions of these documents.

Table A-1

Correspondence of TAMD CRD KPPs to SIAP Attributes

TAMD CRD KPP	**SIAP Attribute**
Completeness (2 of 3 KPPs)	Completeness
Ambiguity: (1)Tracks per Target, (2) Fraction of Tracks Representing Truth Objects	Clarity (1) Ambiguity (Tracks per Object) (2) Spurious Tracks
Continuity	Continuity (1) Longest Track Segment (2) Rate of Track Number Changes
Position Accuracy	Kinematic Accuracy
	Commonality
Timeliness	All Attributes

Table A-2

Correspondence of CID CRD KPPs to SIAP Attributes

CID CRD KPP	**SIAP Attribute**
Probability of ID	ID Completeness
Correctness of ID	ID Correctness
	ID Clarity
Timeliness	All Attributes

The discussion below provides a more detailed description of the attributes and their corresponding CRD KPP where applicable.

Completeness

The TAMD CRD definition of completeness is:

Completeness:

> *The measure of the portion of ground truth tracks that are included in the SIAP. The metrics that describe this attribute are: percent of threat objects in track upon entering the area of influence; percent of total objects in track upon entering the area of influence; and percent of primary and secondary systems, as defined by the scenario, to which tracks are available and exploitable.*

The TAMD CRD provides three KPPs for Completeness, two of which relate to the SIAP attribute of completeness:

> *XX % of (T), YY % (O) of ground truth threat objects detected and tracked upon entering area of influence (TBR), and*
> *XX % of (T), YY % (O) of ground truth aircraft objects detected and tracked upon entering area of influence (TBR).*

The SIAP SE TF has provided the following corresponding definition for completeness:

Completeness: *The air picture is complete when all objects are detected, tracked and reported.*

The phrases quoted from the CRD and the SIAP SE TF definitions include the same objects, AOI, and implications, and are essentially identical in intent.

(There is a third KPP metric for Completeness in the 2001 TAMD CRD, which the 2003 revision proposes to remove.)

(Clarity) Ambiguity

The TAMD CRD definition of ambiguity is:

Ambiguity:

> *The measure of the clarity of tracks in the SIAP. The metrics that describe this attribute are: average number of SIAP tracks/air objects at any given time; and percent of network tracks that represent distinct ground truth objects.*

The TAMD CRD provides the following KPPs for Ambiguity:

XX (T), YY (O) SIAP tracks per air object (TBR)
XX % (T), YY % (O) of tracks represent distinct ground truth objects (TBR) .

The SIAP SE TF has provided the following corresponding definition for clarity:

Clarity**:** *The air picture is clear if it does not include ambiguous or spurious tracks.*

Ambiguous Tracks**:** *Tracks are ambiguous when more than one track, assigned to the same object, is displayable to some participant.*

Spurious Tracks**:** *A track is spurious when it is not assigned to any object.*

The SIAP SE TF definition of clarity is intended to be more explicit than the TAMD CRD definition; furthermore, the issue of spurious network tracks is separated from the issue of ambiguity (dual tracks).

Continuity

The SIAP SE TF has provided the following definition for continuity:

Continuity**:** *The air picture is continuous when the track number assigned to an object does not change.*

Accuracy

There are multiple mission-dependent definitions of accuracy in the TAMD CRD and CID CRD, but no mission specific definition for air objects. An example of a mission-dependent definition is as follows for BMD:

Impact point accuracy*:*

> *The distance from actual missile impact to predicted missile impact point. Methodologies for establishing impact point accuracy may take a number forms: An ellipse with uncertainties along the semi-major and semi-minor axes, an azimuth "wedge" subtended by minimum and maximum predicted range limits, a geometric figure that contains impact point predictions and associated errors from all early warning elements.* (USSPACECOM)

The TAMD CRD provides the following KPP for accuracy:

Impact Point Accuracy (XX seconds after BO)	≤ YY km radius circle with a ZZ confidence (T)
Impact Point Accuracy: (at > XXX seconds to impact)	≤ YYY km diameter circle (T), YYYY km radius circle (O) with a ZZ confidence (O)

The CID CRD also refers to position or geo-location accuracy but currently only specifies the acceptable allowance for increased error due to transmission of CID information.

Geo-spatial Accuracy: *"CID systems must be sufficiently accurate to precisely correlate characterizations among multiple closely spaced surface targets."*

Geo-spatial accuracy will be met if all participants can correctly correlate with network tracks. Thus if participants are not generating dual designations and not miscorrelating tracks then they must be meeting the CID requirement for geo-spatial accuracy.

The SIAP SE TF provides for a combined position and velocity definition of accuracy as follows.

***Kinematic Accuracy*:** *The air picture is kinematically accurate when the position and velocity of each assigned track agree with the position and velocity of the associated object.*
The desired value of the track accuracy is mission-dependent.

Timeliness

As discussed in Section 2.3.1.5, timeliness is not included as one of the SIAP attributes. The current TAMD CRD does not specify a standard for the timeliness of track data and the Information Exchange Requirement (IER) for track data is still to be determined. If the air picture is complete, clear, and accurate, then timeliness criteria will be met.

Recall that the CID CRD specifies a standard KPP for the timeliness of CID data:

> *The CID process must be accomplished:*
> a. *Soon enough to provide military options including warning and engagement decisions.*
> b. *Without increasing the engagement time for any weapon system more than XX seconds.*

The SIAP SE TF has not assigned a SIAP attribute that corresponds to this KPP. However, as the assessment of warfighter benefits proceeds within the context of specific missions, a Measure of Effectiveness (MOE) will be associated with this KPP to assess whether warfighter needs are being met.

CID Attributes:

The CID CRD provides the following description of combat identification attributes:

> *Combat identification is the process of attaining an accurate characterization of detected objects in the joint battlespace to the extent that high confidence, timely application of military options and weapon resources can occur. Depending on the situation and operational decisions that must be made, this characterization will at least, but will not be limited to, 'friend,' 'enemy,' or 'neutral'. Additional characterizations may be required including class, type, nationality and mission configuration.*

The CID CRD KPPs for the characterization with respect to 'friend,' 'enemy,' or 'neutral' are given below:

(1) CID Identification probabilities are specified for Friends (XX), Hostiles (YY) and Neutrals (ZZ).
(2) CID probability of correct identification for each object or entity characterized by CID Systems QQ% (T), VV% (O).

The SIAP SE TF provides three ID attributes with the following definitions:

ID Correctness: *The ID is correct when all tracked objects are in the correct ID state.*
ID Completeness: *The ID is complete when all tracked objects are in an identified state.*
ID Clarity: *The ID is clear if no tracked object is in the ambiguous ID state.*

The CID Identification probabilities specified in the CRD determine the fractional sizes of the objects that remain unknown. Thus this is a form of completeness of the CID picture, broken out by force allegiance. The correct identification probability as defined in the CRD is a ratio of the SIAP attribute measure for overall CID correctness to that for overall CID completeness; i.e.,

$$QQ = \frac{ID_C}{C_{ID}} \qquad \text{(threshold requirement).}$$

The following rationale of the KPP values is given:

> *Ideally, the CID [systems] should be capable of identifying all detected objects and entities of interest, a high percentage of "unknowns" not being conducive to achieving high levels of military effectiveness and minimizing fratricide and collateral damage. The different thresholds for friend, enemy, and neutral, reflect the following assumptions: a) to avoid fratricide and to expedite command and control, it is important to identify friends, and it should be technologically easiest. b) To identify enemy forces is technologically more challenging; therefore, a lower identification probability will be tolerated in order to achieve the desired probability of correct identification. c) Since the process of identifying neutrals may be the greatest challenge, it has been assigned the lowest threshold.*

APPENDIX B

A General Mathematical Procedure for Averaging SIAP Attribute Measures

This appendix outlines a general procedure for carrying out various levels of averaging and obtaining an overall "roll-up" average for any SIAP attribute measure. All of the averaged metrics defined in Section 2.3 of this report are derivable as special instances of this procedure.

It should be noted that the expression *roll-up metric*, also used in SIAP SE TF Technical Report 2002-007, is not always understood to connote an average, and for certain ballistic missile SIAP metrics the term is used in a different sense. However, for all of the air vehicle SIAP attribute measures discussed in this report, the roll-up always refers to the highest-level average over participants, time, and objects/tracks as appropriate.

To accommodate evaluation of the metrics in simulation environments where multiple runs may be executed (Monte Carlo simulations), averages over runs are also embedded in the roll-up procedures.

It is expected that the user will define the time interval over which the SIAP attribute measures are to be evaluated (and averaged, if appropriate), as well as a schedule of scoring times. When the purpose of the evaluation is to assess compliance with requirements, the interval of evaluation, the division into scoring subintervals, and the scheme for selecting scoring times should be constant for the scoring of all SIAP attribute measures for a given CRS and in accordance with the analysis plan. However, for other diagnostic purposes, a scoring schedule tailored to particular events or objects of interest, or possibly varying between different metrics, may be appropriate. The averaging formalism is therefore set up so as to be indifferent to the time period of evaluation, which may be specified by the user to be object- or participant- or metric-specific.

The general procedure for rolling up a SIAP attribute measure may be described as follows. Suppose a single weighted average value is required for a metric $V_{j,m,n}(t_k)$, the metric being defined in a way that is specific to the object (j), participant (m), scoring time (t_k) and run (n) being assessed. For some values of the arguments, the metric may possibly be undefined (perhaps, for example, if j designates an object on which participant m holds no assigned track). Let the values designated by $W_{j,m,n,k}$ be a set of nonnegative weights which are meaningful and appropriate for all values of (j,m,n,k) for which $V_{j,m,n}(t_k)$ is defined. In the formulae for specific attribute measures which follow in the remainder of this Appendix, the weighting may be by number of objects or events, number of participating units, or reportable object lifetimes, as applicable. By convention, set $W_{j,m,n,k}$ equal to 0 if *either* (1) $V_{j,m,n}(t_k)$ is not defined, or (2) the scoring time t_k is not contained in the time interval(s) of interest for this metric as considered for object j, participant m, and run n. The following roll-up average over runs, objects, participants, and time then simply excludes all measurements which are either not of interest or not defined:

$$V = \frac{\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{n=1}^{N} W_{j,m,n,k} V_{j,m,n}(t_k)\Delta t_k}{\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{n=1}^{N} W_{j,m,n,k}\Delta t_k}, \qquad \text{(B-1)}$$

where K is the total number of scoring time intervals, M the number of participants, J the number of objects occurring in the scenario, and N the number of runs. This formulation has the additional mathematical advantage that the four individual averages that it encompasses can be carried out in any order. This feature allows for considerable flexibility in the definitions of intermediate averages on the way to the final roll-up. For example, if a system time-averaged value V_m specific to participant m is required, one simply omits the summations over m in the above formula. The final roll-up value V can then be re-formulated as a weighted average of the individual V_ms over participants, with the weights being $\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{n=1}^{N} W_{j,m,n,k}\Delta t_k$. Alternatively, if an instantaneous IADS average $V(t_k)$ over participants is required, this can be calculated from the formula obtained by omitting the sums over k in the general roll-up formula. The roll-up value V is interpreted as the weighted average of the individual $V(t_k)$s over scoring times, with the weights now given as $\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{n=1}^{N} W_{j,m,n,k}$. The flexibility as to intermediate averages may prove useful, not only for various supplementary analysis purposes, but also in adapting the attribute measures to support differing interpretations of CRD requirements (until a common understanding is reached) or changes to the requirements themselves in future CRD updates.

The identity of the weight factor $W_{j,m,n,k}$ for a given attribute measure may be ascertained from the formula defining the fundamental instantaneous metric for the attribute (in the case of continuity, the object-specific metric) in the body of this report. As a specific example, for the instantaneous system measure of Ambiguous Tracks given in equation 4 (one of the clarity attribute measures), assuming for simplicity that the measure is evaluated for a single run (n=1), the weight factor $W_{j,m,1,k}$ is the number of objects tracked by participant m at the k^{th} scoring time – $JT_m(t_k)$ – and is independent of the index j. That is, the weight is given by the denominator in the expression for the instantaneous system metric $A_m(t_k)$ in equation 4. The application of the general procedure to this case is as follows. The sums over runs (n) in the equation B-1 do not apply since n has only one value, and the sums over objects (j) have no effect since both the weight factor and the instantaneous system metric are defined independently of j.

Applying the sums over time steps (k) alone produces the time-averaged system metric as in equation 5:

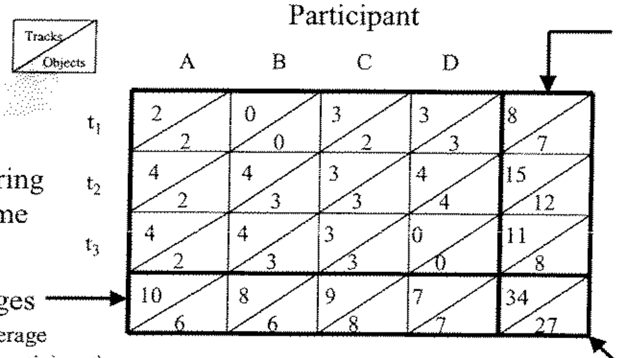
$$A_m = \frac{\sum_{k=1}^{K} JTm(t_k) A_m(t_k) \Delta t_k}{\sum_{k=1}^{K} JTm(t_k) \Delta t_k} = \frac{\sum_{k=1}^{K} NAm(t_k) \Delta t_k}{\sum_{k=1}^{K} JTm(t_k) \Delta t_k} , \qquad \text{(B-2)}$$

while separately applying the sums over participants (m) alone produces the instantaneous IADS metric:

$$A(t_k) = \frac{\sum_{m=1}^{M} JTm(t_k) Am(t_k)}{\sum_{m=1}^{M} JTm(t_k)} = \frac{\sum_{m=1}^{M} NAm(t_k)}{\sum_{m=1}^{M} JTm(t_k)} . \qquad \text{(B-3)}$$

The roll-up metric A of equation 6 (a specialization of equation B-1) may then be interpreted as a weighted average of A_m over participants, or a weighted average of $A(t_k)$ over time steps. The invariance of the roll-up metric with respect to the order of averaging is illustrated by the numerical example displayed in Table B-1. The term “track” in this table is understood to mean an assigned track, and “object” is understood to mean a tracked object (that is, a reportable object to which at least one track is assigned). The notation x/y in a table entry means x tracks and y objects (that is, x assigned tracks and y tracked reportable objects). A 0/0 entry signifies any of the following cases: that there were no tracked objects (and thus no assigned tracks), that no data was available for the given participant at the given time, or that the participant was attritted by the given time. Every averaging step consists of independently summing the track and object counts in the table entries, either across a row or down a column of the table. Scoring is assumed to be at uniform time intervals.

Table B-1: Sample Averaging Calculations for Ambiguous Tracks



Participant

Tracks/Objects

		A	B	C	D	
Scoring Time	t_1	2/2	0/0	3/2	3/3	8/7
	t_2	4/2	4/3	3/3	4/4	15/12
	t_3	4/2	4/3	3/3	0/0	11/8
System Time Averages		10/6	8/6	9/8	7/7	34/27

Instantaneous IADS Averages
(object-weighted average over participants at each scoring time}

System Time Averages
(object-weighted average over time for each participant)

"Roll-up":
34/27 ≈ 1.26
(derivable from either the system averages or instantaneous averages, through the same averaging procedure)

All of the SIAP attribute measures discussed in the body of this report, with the exception of the kinematic accuracy measures, follow exactly the same procedure with respect to averaging. The slight exception for kinematic accuracy arises from the use of RMS averages for position and velocity errors, in accordance with standard practice in error statistics. However, if the *squares* of the position and velocity errors are regarded as the fundamental metrics of interest, then the squares of the kinematic accuracy attribute measures defined by equations 15-22 follow exactly the pattern laid out above.