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EXPLORING C4ISR EMPLOYMENT METHODS

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ABSTRACT

We will investigate several employment schemes for Command, Control, Intelligence Surveillance and Reconnaissance (C4ISR) collection assets in a simulated Force combat model. These collection assets include Unmanned Aerial Vehicles (UAV) and any ground platforms, normally part of a conventional coalition force lay down. Samples of ground assets include: armored personnel carriers (APC), helicopters, tanks, trucks, binoculars and eyes. Collection asset performance characteristics, along with obtained sensor scans, enable probabilistic identification of participating adversaries or their weapon systems. Comparative analysis focuses on the time to initial enemy observation, threshold of commander's critical information requirements met, and prevention of collection asset loss rate. The analyst controls all thresholds via the user interface. Additionally, a paradigm for information management, i.e. intelligence fusion, is presented. We explore procedures for reducing data volume within this paradigm. We will also discuss implications for the coordination of simulation, analysis, and acquisition activities.

1 INTRODUCTION

The ISR collection assets implement a collection management plan. The analyst sets the objectives of a particular simulation. These objectives then control the behavior of the ISR assets and can influence the decision-making capability of the entities on the battlefield.

This paper guides us through scenario development. We then discuss the technical characteristics represented in simulation model, and it's corresponding input and output. The ISR asset behaviors are shown in figures 1 to 4, while the implemented methods for analyst control of ISR asset behaviors is shown in figures 5 to 7. A method for revising the data set is presented, followed by a user interface for controlling the fusion process. We also consider factors for computing time and logistics to perform C4ISR refinement. Some helpful simulation verification indicators are provided.

The required inputs exist in a large database of combat systems, as well as their technical performance characteristics. The same database, that contains the technical characteristics of the combat systems, also captures all of the probabilistic target information in its environment. The constraints, placed on both the combat systems and the ISR sensors, are also in the database. The combat systems serve as targets for coalition forces, as well as the coalition force itself. Performance parameters for systems modeled are obtained from multiple agencies, including the Army Material Systems Analysis Agency (AMSAA) and the National Ground Intelligence Center (NGIC). Guidance on utilization of ISR assets is provided by AMSAA or NGIC (*Unit of Action (UA) Sensors by Echelon*, 2004). Parameters for known systems are detailed in nature. On the other hand, parameters for unknown or planned future systems must be estimated and agreed upon by the agency supplying the information. A by-product of this estimation process is the capability for exploratory analysis on the impact of differing performance parameters within the model.

The outputs of the simulation yield the size of corridor, in X-by-Y kilometers, that could be diagnosed using (1 to n) airborne ISR assets. The analyst also can set the timeframe, in which data reception and fusion must occur, in order for the combat commander to act upon it. The simulation attempts to meet the coalition's combat objectives, without incurring losses of equipment and personnel. Default settings achieve a balance between winning the close-in fight vs. monitoring targets deep within the battlefield. The analyst adjusts the spatial and temporal data, concerning the desired ISR collection set, if the default settings don't yield satisfactory results.

2 SIMULATION TASKS

Although the simulation gets complex, because it takes into account the varying factors that determine the sensor's performance in the relevant environmental conditions, the software has been designed to work with generalizations of all sensors employed. Some of the geometric computations, regarding the sensor's ability to find targets are necessary for all sensors Each entity invoked then adds the technical characteristics specific to the sensors employed.

2.1 Scenario Development

Much of the effort of the analysis is the scenario development the analyst performs. The simulation considers the adversary's combat equipment holdings as acquisition targets.

Non-combatants can be modeled with several different roles. Sometimes the non-combatants become victims of attrition, even though they are not part of conventional battlefield adversaries. The non-combatants also serve as informants, as part of HUMINT, or use receiving and processing equipment to correlate the ISR data collected in any intelligence discipline, including HUMINT.

Employment of C4ISR assets is generally focused on targeted areas of interest (TAI) or named areas of interest (NAI). Intelligence analysts determine TAI and NAI locations by scrutinizing parameters to include terrain and probable enemy actions. Under this employment method, obtained information often confirms the intuition of the intelligence analyst.

2.2 Representing Technical Characteristics

Only a subset of ISR asset characteristics is described herein. A full description of user-defined settings, and how they are predicted to improve the scenario's outcome, can be found in the simulation's user manual.

A typical airborne sensor's projection is shown in Figure 1. The sensor's projection could be rectangular, elliptical, donut-shaped, or some irregular shape. The boresight, shown as θ, is the pointing direction of the sensor in azimuth and elevation. The boresight limitations are provided by AMSAA or NGIC. The boresight translates into field-of-regard (FOR). The sensor's projection translates to field-of-view (FOV) of a sensor. Both FOR and FOV could be reduced due to other physical devices mounted on the same platform or electronic interference in the operating environment.

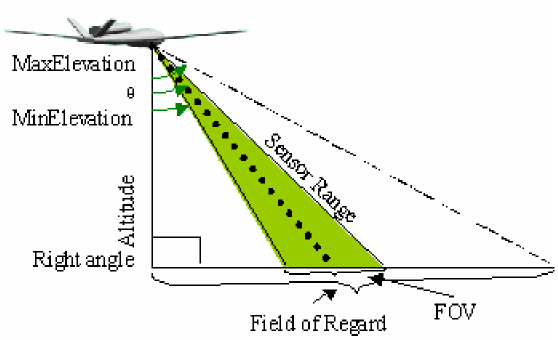

Figure 1: Airborne Sensor Projection

The relationships in the database, between systems on the platform, limit all of the platform's sensor behaviors. Simply utilizing one table of information to represent an individual component's technical characteristics won't suffice to allow an analyst to provide a viable and feasible solution set.

A subject matter expert can tell you that there is no such thing as a perfect geometrically shaped sensor projection. Whether the sensors are passive or active, and regardless of the technical characteristics of the sensors, the ability to detect targets occurs in a concentrated spatial area. The disparity of technical performance vs. simulation model representation is resolved when the in-house subject matter experts from AMSAA or NGIC provide probabilistic object discrimination. The object discrimination categories are shown in the reference document (Klein 2004), as detection, orientation, classification, and identification. The levels of object discrimination that are most prolific are classification and identification. Classification is the knowledge of the presence of an object: building, truck, tank, trees, field, etc. While identification is described to the limit of an observer's knowledge: mosque, pickup truck, T-72 tank, M-105 Howitzer, etc. Taxonomy of computational algorithms, used to reach each of the object discrimination levels, is also presented in the reference document.

2.3 ISR Asset Behaviors Modeled

The description to follow, explains the behaviors programmed into the simulation. The scenario, shown herein, depicts the initial ISR collection performed by airborne ISR assets. Ground assets can supplement these airborne assets, to cover airfields or other critical fixed areas of interest.

The coalition force lay down can be divided into sectors, as shown in Figure 2. The number of the sectors and size of each sector can be changed by the analyst.

The enemy's location is not known at the commencement of the conflict. We could argue that, if we already know where the enemy is, we don't need any ISR assets to find it. However, we don't have to start at zero knowledge state. We could have some priority targeting of known fortifications that are likely to be troubling.

Without loss of generality, the enemy is located due East of the coalition forces. The enemy combatants can penetrate the coalition's forward edge of battlefield advance (FEBA), either physically or via electronic interference or sabotage. The boundary condition, representing the furthest geospatial coordinates of coalition force lay down, upon commencement of a battle or campaign, will be used in setting the ISR collection assets initial positions.

The starting longitude of the airborne ISR asset is determined by random draw or can be specified to meet analysis objectives. It always starts somewhere within the current FEBA width.

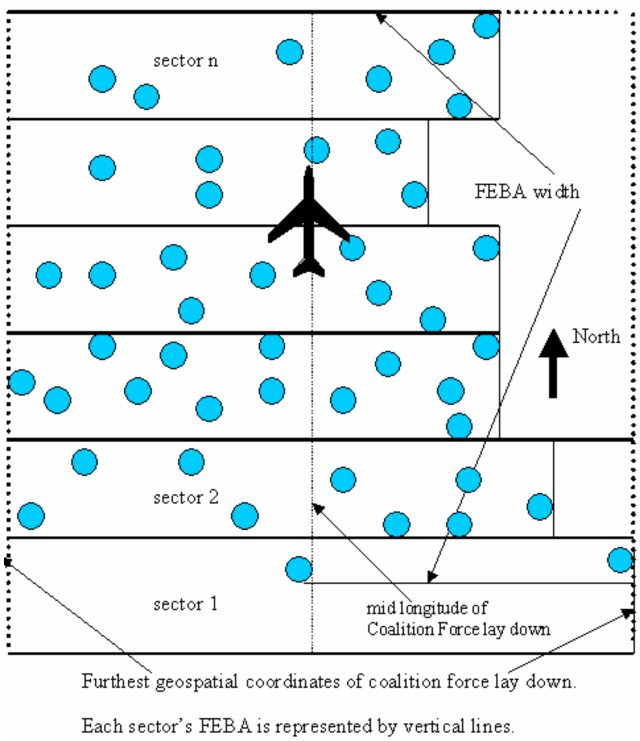

Figure 2: Coalition Force Lay Down

Another random draw determines whether the ISR asset travels North or South. The size of corridor to diagnose is set to the area of responsibility of the combat commanders.

The sensor's projection, as the airborne platform moves, is shown in Figure 3. The sensor projection is shown in gray for area already swept, and in green for the current sweep. The simulation uses the probabilistic data values for object discrimination, for all entities that exist within the sensor's footprint. In other words, if the entity is in the target list, and it's ground truth location is within the sensor's rectangular representation of the footprint, the probability of detecting the entity, in it's environment, is the data value provided by AMSAA or NGIC.

The simulation delays further sweeping of the sensor, as the ISR asset turns around and recomputes boresight. The boresight is recomputed every time the platform heading changes and at least one sensor on that platform is going to commence sweeping its designated scan area, with built-in error checking verification.

Some airborne ISR assets will not be able to project their sensor's footprint to a requested location, due to technical performance characteristics of the sensor or due to other battlefield priorities set by the analyst. There are three cases for alternative operational plans implemented in the simulation software model.

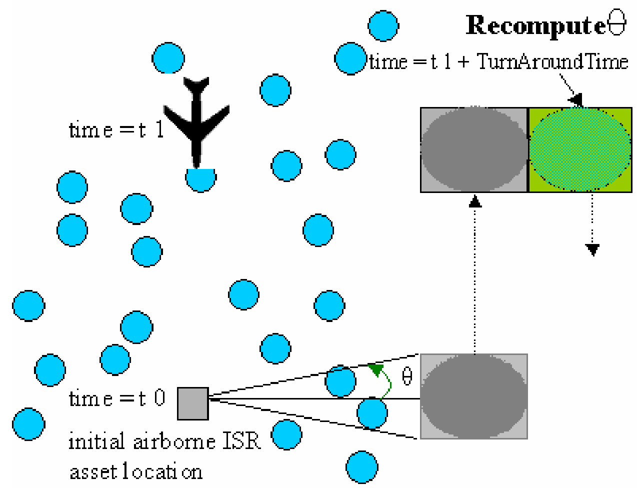

Figure 3: Sensor Projection During Flight

2.4 Implemented Methods for Analyst Control of ISR Asset Behaviors

The methods, that have been implemented, to allow the analyst to control the ISR asset behaviors are described in three circumstances.

1. Rather than remaining at mid longitude of the initial coalition force lay down, it may be beneficial to alter the flight path with new air tasking orders. If the sensor cannot project to the desired location for sweeping, the analyst can set the minimum distance behind the coalition's FEBA where the airborne ISR asset must fly. There might not be a minimum distance if it more readily meets objectives in front of the coalition force FEBA, with known risks. However, a default minimum distance is set, until the analyst resets its value.
2. Figure 4 shows what happens in the simulation when the sensor sweeps for time = t (n), but none of the desired information is discovered. The condition is defined with the auto retasking properties, set by the analyst. The retasking order might occur due to the following reasons
   a. Finding an empty data set when sweeping
   b. Obstructions blocking reception of desired information
   c. Needing a resource to do higher priority task

   The green arrow represents the new flight path of the airborne asset. This new flight path is NOT achieved instantaneously in the simulation. The aircraft's speed, current heading, and turn around time (if a turn around is necessary), determine how fast the aircraft arrives at the new location. The new flight path is set by another random number draw, but could alternatively act upon the fusion process results of the ISR data collected.

3. After more definitive guidance is provided by the owners of the ISR assets, the simulation model could implement additional behaviors. A significant amount of research is occurring, to address predictive analysis challenges (Intelligent Software Solutions, 2005 and Romano 2004). The industry experts are also resolving mission planning and deconflicting airspace issues.

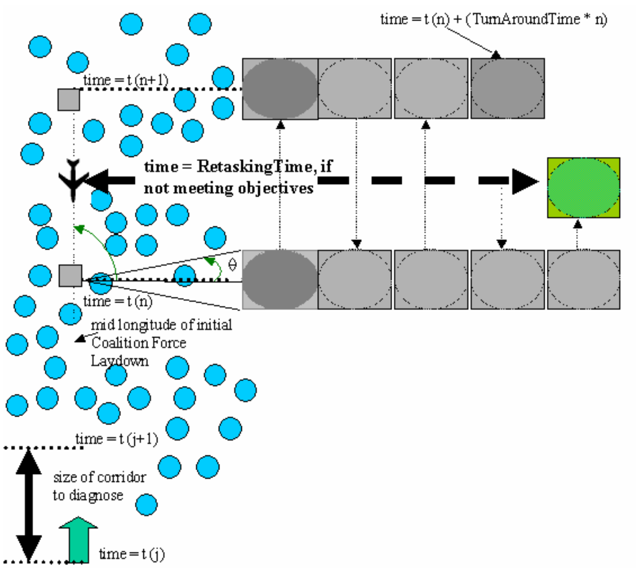

Figure 4: Retasking

2.5 Method for Revising the Data Set

An animation of targets detected is shown in a two dimensional visualization tool. This visualization aids the analyst in deciding how and when to modify simulation behaviors.

A sample data set is provided in a "pull" from the database, in the Appendix. More specific criteria for searching for targets can be set by the analyst utilizing the simulation user interface, shown in Figure 5, 6 and 7, if the generalized target set won't provide the desired level of battlefield awareness.

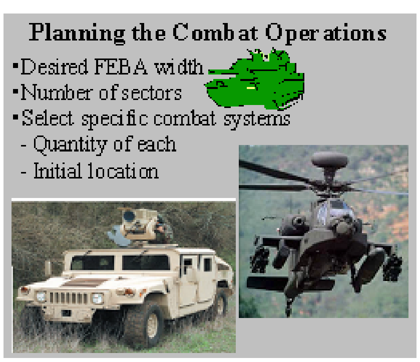

Figure 5: User Interface, Planning the Combat Operations

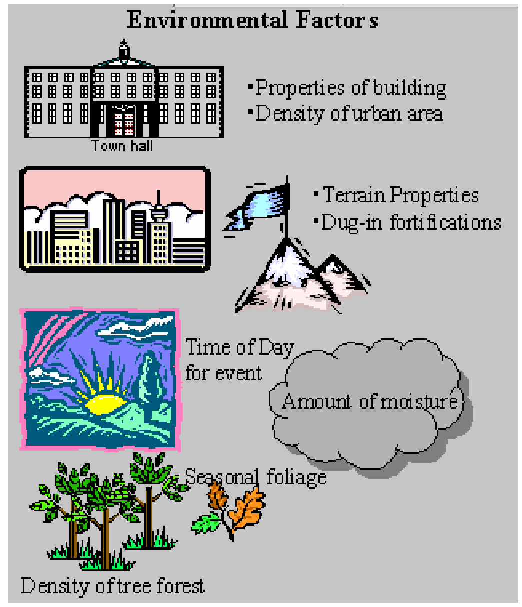

Figure 6: User Interface, Environmental Factors

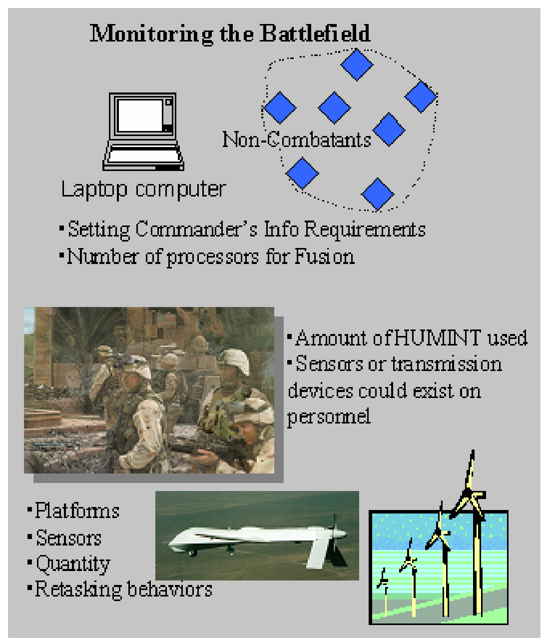

Figure 7: User Interface, Monitoring the Battlefield

3 CONTROLLING THE FUSION PROCESS

A textbook definition of fusion is "a process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance (Llinas and Hall)". Whereas, a military definition of actionable intelligence is "a series of processes performed to transform observational data into more detailed and refined information, knowledge, and understanding (Walsh)".

The ISR data collection process attempts to address fusion issues in the simulation. We don't want bulk data about the environment, only actionable intelligence. We can use the simulation as a tool to gain an understanding of how to control the floodgates of data.

There is an ongoing debate on the reliance on the network centric warfare being fully implemented (Kaufman). Demanding excessive cross cueing of sensors can stymie the decision making process. All of the correlation and translation requirements, as well as individual processing delays won't provide timely information. A database user interface, shown in Figure 8, is used to set simulation thresholds for data collection and fusion.

All of the data collection results are accumulated during simulation run time, however most of it is considered as merely internal record keeping bulk data. Assessment consists of ascertaining the uncertainty level to determine the plausibility of the evidence.

Taxonomy of state estimation and tracking algorithms is shown in the reference document (Klein 2004). The association and correlation of data and tracks is presented, along with metrics for deriving predictive information.

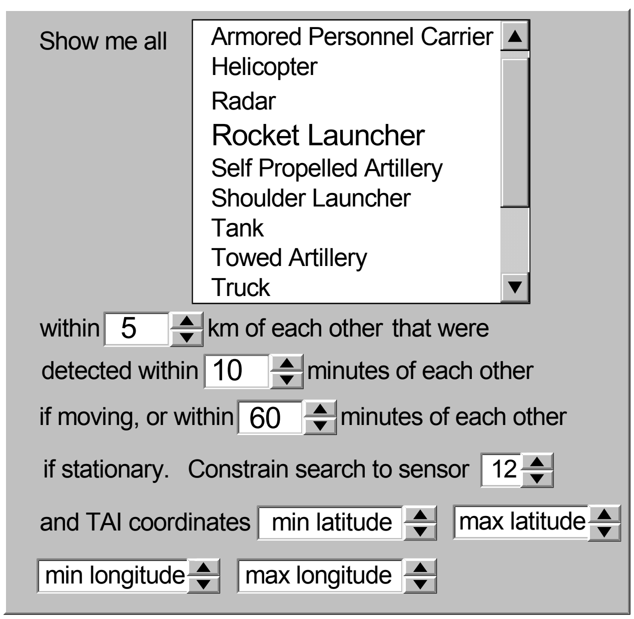

Figure 8: User Interface, Fusion Constrains User Interface

4 FACTORS FOR COMPUTING TIME AND LOGISTICS TO PERFORM C4ISR

An explanation of time and logistics required to perform and refine C4ISR is offered. Table 2 sets the stage for conducting an experiment for our attempted increase of battlefield awareness level. The probability of object discrimination level being obtained has unclassified data in Table 2, and can be refined using secret or top secret data, using technical sensor and target characteristics.

The generalized class of targets has a 90 percent probability of being detected, with the low resolution setting. Using the same sensor, there is a lower probability to recognize a specific target of that target class, as shown in row 1 and 2 of Table 2. Note that some fusion would be required, and supplemental ISR collection assets might be required to improve the confidence level in the intelligence data.

The software simulation can compute how long it takes to use the high resolution sensors to refine the battlefield awareness of a particular corridor. Pragmatic considerations may encourage the analyst to use the simulation model with an embedded forward observer on the ground. Table 1, in the appendix, lists eyes and binoculars as sensors on the battlefield. Plenty of data is available on the technical performance characteristics of these valuable resources, at AMSAA.

All sensors in the simulation are initially set to the low resolution setting. Upon performing fusion, if a threshold is exceeded, several alternative actions are performed.

1. The scarce high resolution sensor can be utilized. The decision to use the same low resolution sensor that found the desired information, and reset to high resolution, can be made. When the airborne ISR asset reaches its next waypoint, it is automatically repointed to revisit the area where the desired information was found.
2. The simulation utilizes a ground ISR asset, either to revisit an area of interest or to cover ground that can't be covered using an airborne ISR asset. Once the locations of enemy fortifications are known, we can devote more ISR assets to monitoring it.

The software model, which is the subject of this document, allows for the exploitation alternatives to be explored.

5 VERIFICATION INDICATORS PROVIDED

The first step in troubleshooting results is the verification of internal record keeping. Text files are output at simulation time, to verify that the software is behaving as instructed by the analyst. The internal record keeping is triggered whenever thresholds are exceeded.

Sometimes there are multiple platforms, which use the same platform name or sensor name. Each entity has a platformID or sensorID assigned to it, once it is created in the simulation. Sometimes the platform has multiple values for the operating characteristics, such as: speed, altitude, sensor's sensitivity level setting, and can be set to different values by the analyst at the user interface. The simulation automatically keeps track of all attributes of the platforms and sensors being played. Additional information about what was found, using the sensor suite, is provided as output in text files. Some sample verification information is shown below.

- Found desired information
  - Target classification name or specific target data, if requested by the analyst
  - ISR asset Name: PlatformID, SensorID
  - Level of information obtained: detection, recognition, identification
  - XYZ coordinates of target
  - Target location error
  - Target velocity error
  - Time in minutes = time of Intel data item collected
- No detections are made, but other notable conditions exist
  - Obstruction found at location XYZ coordinates.
  - No change from previous state (same building still there)
  - Empty data set collected for too long. The simulation is going to perform auto retasking.
  - Reached waypoint: waypointID, at location XYZ coordinates
  - ISR asset Name: PlatformID, SensorID
  - Time in minutes = time of Intel event, or reveals time that expired for empty data set
- Mission Requirements Attributes
  - Commander's critical information requirements (CCIR) satisfied at current time, with combat commander ID
  - Retasking settings for ISR assets, set by mission or by sensor employed
  - Level of fusion requested, which is derived from the confidence level of data obtained via multi-Intel sources. Properties of fusion may equate to sensor cross cueing or information dissemination rule set of data collected.

6 CONCLUSION

The simulation results of the software tool, and its employment methods of utilizing ISR assets, yield some pragmatic battlefield advantages. The software simulation tool, which is the subject of this paper, allows an analyst to determine the number of resources required to maintain timely actionable intelligence. The analyst controls this process, and obtains a reasonable and feasible amount of ISR assets required.

APPENDIX: SENSORS AND TARGET SETS ON THE BATTLEFIELD

The set of adversarial combat systems become target sets for opposing sensors. A sample data pull, from the database, is shown in Table A-1. Electro optical (EO) sensors have subcategories eyes and binoculars. EO often has operating modes auto target recognition (ATR), or auto identification.

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TERRI CHANG currently serves as software developer at The US Army, Center for Army Analysis, in Fort Belvoir VA. She has eighteen years of experience developing hands-on problem solving analytical toolsets. These software toolsets have been used in the mobile satellite communications industry, as well as the Office of Naval Intelligence (ONI), SPAWAR. Ms Chang has participated in numerous feasibility study teams, with in-theater UAV for ISR data collection, sponsored by Defense Airborne Reconnaissance Office (DARO) and Defense Advanced Research Project Agency (DARPA). She holds a B.S. in Electrical Engineering from The Pennsylvania State University. Her email address is terri.chang@us.army.mil.

Table A-1: Sample Pull from Database

Discipline	Sensor Type	Platform	PlatformType	Target Categories
IMINT	SAR	Predator, A160 Hummingbird (2 kinds), ACS, U2, TUAV, UAV Class IVA, UAV classIVB, Global Hawk, JSTARS, Space-based Radar (SBR) constsellation	airborne	Armored Personnel Carriers, Rocket Launchers, Self-propelled Artillery, Tanks, Trucks, …, others.
IMINT	EO *, IR	Predator, A160 Hummingbird, ACS, TUAV, UAV Class IVA, UAV classIVB, Helicopters (OH58D, AH64D), Tanks (Stryker, MCS, R&SV, M1A2 SEP), Unattended Ground Sensor (UGS)	airborne, ground, (other platform attributes: stationary, moving platforms)	Armored Personnel Carriers, Towed Gun, Rocket Launchers, ..., others
MTI	MTI	Predator, A160 Hummingbird (2 kinds), ACS, TUAV, UAV Class IVA, UAV Class IVB, Global Hawk, RAH66, Space-based Radar (SBR) constellation	airborne	Many targets, at wide range of speeds
MASINT	Magnetic, Seismic, Acoustic, Ground penetrating Radar (IR)	Multiple configurations on UAV, ground vehicles, unattended ground sensors	ground,(other platform attributes: stationary, moving platforms)	Mines, Armored Personnel Carriers, Helicopters, Tanks, Trucks, Troops
SIGINT	ELINT,COMINT	ACS, Rivet Joint, TUAV,UAV Class IVA, UAV class IVB, U2, WECM receiver, Ground vehicles (GV)	airborne, ground, (other platform attributes: stationary, moving platforms)	(listed by purpose): Tracking, Mortar Artillery detection and tracking, Acquisition, Battlefield surveillance and management
SIGINT	COMINT	ACS, Ground vehicles (GV), Prophet, Rivet Joint, TUAV, UAV Class IVA, UAV class IVB	airborne, ground, (other platform attributes: stationary, moving platforms)	specific comm devices listed
Radar	Radar Cross Section (RCS)	TUAV, UAV Class IVA, UAV class IVB, ACS, JSTARS, Global Hawk	airborne	Vehicles (Tracked, Wheeled, Towed), Helicopters, Fixed Wing Aircraft, Missiles, Counter Battery
Radar	Counter Fire Radar Detection			

Table A-2: Factors for Computing Time and Logistics to Perform C4ISR

Resolution Setting	Level of Object Discrimination	Probability of Object Discrimination Level Being Obtained *	Target Set	Time and Logistics Factors
Low	Detection	90	Generalized Class	• Computed by ISR collection asset ability • Influenced by environment or clutter • Fusion required
Low	Recognition	60	Specific Target	• Computed by ISR collection asset ability • Influenced by environment or clutter • Some fusion required • Supplemental ISR collection asset utilized
High	Recognition	80	Generalized or Specific Intel requested	• Auto target recognition mode possibly used • Communication of Intel required • Sensor footprint, FOV, reduced • Sensor maximum range reduced • High resolution sensors availability reduced
High	Identification	70	Specific Target Characteristics	• All of the above required • Planning and coordination of alternative course-of-action for the existing combat force deployed, along with all combat support logistics required