Analytical Modeling in Support of C4ISR Mission Assessment (CMA)

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Abstract

The authors were recently involved in a major study, the C4ISR Mission Assessment (CMA), conducted to develop an investment strategy in support of the Quadrennial Defense Review. In conducting that study, we developed a framework for analysis of C4ISR issues and we developed a family of decision support tools for quick response analyses and which would focus on the specific issues of interest to CMA. Those tools were used to evaluate alternative C4ISR mixes and to make a variety of analysis excursions.

The use of desktop tools that rely on analytic techniques for fast calculation, evaluation of parameter interactions, multi-parameter optimization, and simplified risk analysis proved extremely valuable for the support of the CMA quick-look analyses. This highly aggregated analysis technique is useful for quickly identifying sensitive parameters and for evaluating the performance envelope of alternative architectures of C4ISR and weapon systems.

This paper discusses the analysis framework and the family of models developed to support CMA analyses. Illustrative examples of the analyses results are provided.

[1] Sponsors for this work are ASD (C3I) and Joint Staff (J6).

1. Introduction

The C4ISR Mission Assessment was a joint government, FFRDC, and contractor effort under the direction of Mr. Richard Mosier of CISA with MITRE as the technical lead. The purpose of CMA was to develop an investment strategy for C4ISR to support the QDR. This paper discusses part of the activities of the CMA. The major objectives were to evaluate alternative C4ISR portfolios; to provide analytical assistance for addressing specific tradeoff decisions; and to bring analytical methods to bear to substantiate or deny the conclusions and recommendations of 'Quick Look' assessments.

1.1 Analysis Infrastructure

It is widely acknowledged that the available decision support tools are inadequate to support the requirements for studies and analysis of C4ISR issues[2]. Therefore, to achieve the above objectives, CMA would have to develop an infrastructure[3] for supporting analysis of C4ISR issues. This infrastructure would consist of the following elements:

- Scenarios
- Databases
- Measures of merit (C4ISR measures of performance (MOPs) and measures of effectiveness (MOEs))
- Desktop analysis models[4]
- Reference library of C4ISR studies and analyses

1.2 Activities

The efforts supported by the authors of this report included the following ten activities:

- Interaction with the Force Mix Studies
- Scenario space and risk analysis
- Scenario development
- Campaign mining
- Focused reports
- MOP/MOE development
- Database development
- Model evaluation
- Desktop model development
- Analyses

Figure 1 illustrates some of the relationships among these activities and shows how the activities supported the efforts of some of the other CMA tracks.

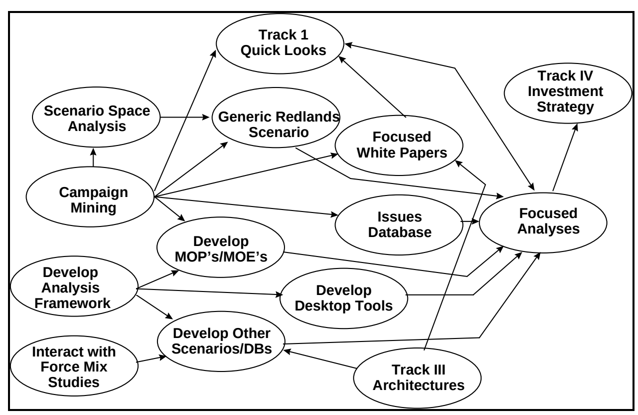

Figure 1. Relationship of Activities

Only a portion of these activities are discussed in this paper. Additional information may be obtained from the study sponsors (CISA or J6).

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[2] The inadequacy of existing tools to support C4ISR studies and analyses was one of the conclusions of the 1995 C4ISR Decision Support Task Force and was one of the major reasons for the decision to develop the JWARS simulation model.

[3] We viewed the 'infrastructure' as a start towards what would be required for providing long-term support for C4ISR acquisition and analysis – not a one-time effort to support only the CMA. For example, the infrastructure should support future efforts of the C4ISR Decision Support Center.

[4] Because of time and resource constraints and the desire to be able to examine many excursions, we realized that we would have to rely on rather simple models that would execute rapidly and would run on PCs. We refer to such models as 'Desktop Models' to distinguish them from larger, resource intensive simulation models such as TACWAR, VIC, EADSIM and the like.

2. C4ISR Deficiencies in Legacy Decision Support Tools

The C4ISR Decision Support Task Force (DSTF) determined that there were many modeling and simulation tools used to support C4ISR analyses, but that the existing tools have significant weaknesses in areas important to C4ISR modeling. In large part, the deficiencies stem from the fact that most of the current models were designed to evaluate combat -- not to address C4ISR issues. Such models developed for the purpose of evaluating combat using Lanchester equations or other mathematical approaches are not well suited for analysis of C4ISR. Most of the information processes so important to C4ISR are modeled poorly, or not at all, and the list of C4ISR-related deficiencies is large. Some of the major deficiencies are summarized below:

- Measures of effectiveness are inappropriate for evaluation of C4ISR.
- Tools do not adequately relate the contributions of C4ISR to effectiveness on the battlefield; changes in specific C4ISR systems or performance differences cannot be traced to changes in combat outcomes.
- C4ISR is usually modeled in a trivial way assuming perfect knowledge, perfect information on enemy and own troops, and perfect communications (time delay is often the only factor which reflects a reduction in C4ISR performance).
- C4ISR systems on the battlefield are generally modeled implicitly by assuming that the intelligence gathering, processing, fusion, communications, and command decision making processes are perfect.
- Decision support tools do not allow for factors such as unreliability or information overload.
- “Ground truth” location of friendly entities is a given in most models.
- Models generally assume perfect battle damage assessment and ineffective enemy deception.
- Most models and simulations do not realistically model the influence of weather, terrain, and the environment on the performance of sensors and C4ISR systems. For example:
  - It’s common to assume that the earth is like a billiard ball (i.e., clear weather, smooth earth surface, no vegetation, or other significant environmental factors).
  - Even models that do include these parameters to some degree do not include space-based sensors with the capability to monitor and transmit this information.
- The modeling of communications in theater and engagement models is generally unrealistic due to:
  - lack of environmental influences on communications, unlimited bandwidth, no lost or ambiguous messages, no interference, no fog of war, and no time delays,
  - linkages through which communications are transmitted and received are usually invisible in the models.
- Few tools incorporate multiple intelligence disciplines and even fewer allow direct comparisons of different systems..
- Few tools link models of the intelligence cycle with operations models or force-on-force models to assess the impact of ISR on warfighter effectiveness. For example:
  - intelligence simulations almost always use static definitions of users’ needs that do not correspond to the dynamics of theater warfare models,
  - operational combat models usually naively represent intelligence capabilities, either assuming perfect

intelligence, no intelligence or static intelligence (e.g., 75% of the targets are known),

- most models do not account for the changing amounts and value of intelligence in different phases of campaigns,
- few of the tools effectively model the effect of intelligence on C2; intelligence may affect the probability of kill or attrition rates, but it rarely affects the commanders' decisions in fighting the war.

3. Requirements for Models and Simulations to Support C4ISR Analyses

C4ISR decision support is about knowledge, not platforms and systems. It addresses the collection, processing, dissemination, and use of information and intelligence by any decision-maker to act at the time and place of his choosing. Thus, the tools that one uses to address C4ISR issues must allow these activities to be addressed. Furthermore, since we want to explore a wide variety of parameter values in the scenario space, the tools need to address the parameters of interest, and the model must run fast enough to allow the analyst to explore hundreds of different parameter combinations. The specific criteria that we used to evaluate decision support tools for possible use for analyses are listed below. While it is probably unrealistic to expect any tool to meet all of the criteria, we do want to satisfy as many as possible.

3.1 Evaluation Criteria

- General Criteria
  - Run on a personal computer or low-end workstation
  - Available for CMA use; government owned, commercial off-the-shelf (COTS), or the proprietary property of one of the CMA contractors
  - Execution times much faster than real time (100 to 1000 times faster than real time)
  - Reasonable resource requirements (manpower, time to set up databases, training, etc.)
  - Run without a human in the loop
  - Flexible with respect to the insertion of new weapons, sensors, tactics, techniques, and procedures
  - Model a variety of military operations and operations other than war
  - Model air, land, sea, space, and littoral regions
- Aggregation/Resolution
  - Represent ground combat units at the company level or below
  - Model up to a brigade level for blue forces and a division level for enemy forces
  - Represent enemy targets in terms of individual entities, or, in terms of entities aggregated according to the Deep Attack Weapons Mix Study (DAWMS) target categories
- Sensor Modeling
  - Model individual sensors of the following types (SIGINT, HUMINT, IMINT [space, airborne, manned, unmanned, EO, IR, SAR, MTI])
  - Represent sensor tasking, collection, processing, exploitation, dissemination, communications, command and control, fire control and engagement
  - Degrade sensor effectiveness due to weather, terrain masking, foliage, and target cover, concealment and deception (CCD)
  - Model sensor cueing
  - Model the fusion of multiple sensors
- Command, Control and Communications Modeling
  - Model communications explicitly with constraints on capacity
  - Allow for degradations in communications due to terrain, weather, and enemy jamming

- Assess robustness and survivability of communications
- Represent command and control nodes
- Assess the impact of various levels of C3 integration and interoperability in joint warfare
- Model sensor-to-shooter strings

- Information
  - Assess the impact of timeliness and quality of information on warfighter effectiveness
  - Provide the capability to assess the value of information and situation awareness
  - Support the computation of the TAR measure

It is unlikely that any legacy decision support tool will satisfy all or even most of the above criteria. The C4ISR DSTF developed 24 functional requirements for C4ISR decision support tools and concluded that only two of the 24 functional requirements were met in full by the existing theater/engagement-level simulations. The criteria listed above were derived in part from those 24 functional requirements.

4. Model Selection

4.1 Models Considered

Driven largely by the "General Criteria" listed above, the SR&C group considered the following theater/engagement-level models:

- Joint Multi-warfare Assessment Game (JMAG)
- COMBAT IV
- METRIC
- Corps Battle Analyzer (CORBAN)
- TACWAR
- Vector in Commander (VIC)
- Joint Integrated Contingency Model (JICM)
- JANUS
- Composite Warfare Model (CWM)
- Naval Simulation System (NSS)
- Integrated Theater Engagement Model (ITEM)
- C4ISR Model

All of the models were rejected as the primary tool for CMA analyses. Although rejected as the primary tool for analysis, the COMBAT IV model was selected for a few specific analyses since it provided an easy target of opportunity. BDM had used COMBAT IV for a recent C4ISR study and it had NEA and SWA scenarios that it could easily modify to support CMA analyses. BDM made a few runs of COMBAT IV to examine 'end-game' combat results such as movement of the FLOT, attrition rates, casualty exchange ratios, and time to halt the invasion.

4.2 Models of Choice

Our evaluation of the existing decision support tools led us to the decision to develop a family of desktop tools that would support quick response analyses, and which would focus on the specific issues of interest. This decision was influenced significantly by the fact that we could build on the CAPSTONE parametric models that MITRE had previously developed to support earlier C4ISR studies, and the fact that several members of the SR&C team had experience in developing such tools. The next section describes the family of desktop tools that were developed to support CMA.

5. Desktop Models

5.1 CAPE Family of Models

The C4ISR Analytic Performance Evaluation (CAPE) toolset was developed to quickly evaluate top level architectures over a broad range of scenarios and system parameters. The CAPE toolset consists of five models for analyzing C4ISR systems:

- *Deep CAPE* for deep attack operations
- *Close CAPE* for close combat operations

- *PEDS CAPE* for examining the processing, exploitation, and dissemination of ISR information
- *Dynamic CAPE* for analyzing C4ISR systems in a dynamic environment
- *Geo CAPE* to support situational awareness analyses

All CAPE versions use analytic techniques for fast calculation, evaluation of parameter interactions, multi-parameter optimization, and simplified risk analysis. This highly aggregated analysis technique is useful to quickly identify sensitive parameters and to evaluate the performance envelope of alternative architectures of C4ISR and weapon systems. After scoping down to promising architectures, more detailed (and expensive) discrete event simulation techniques can be employed. Deep CAPE, Close CAPE, and PEDS CAPE were all built using the COTS modeling package, *Analytica*. Dynamic CAPE and Geo CAPE were built using the COTS simulation package, *EXTEND*.

The five versions of CAPE emphasize different missions, treat geography at different resolutions, and treat time differently. Deep CAPE models the theater deep strike mission with time snapshots at various time phases. Weapon target pairing is performed and targets at risk are calculated. Close CAPE emphasizes the close battle in a division size slice of the ground and air battle. Performance is calculated at different phase snapshots. PEDS CAPE models theater and CONUS processing exploitation, and dissemination of satellite and airborne imagery.[5] Communication delays and throughput are calculated and time is treated continuously. Dynamic CAPE is similar to Deep CAPE but treats time continuously and calculates sensor and strike platform attrition. The impact of different deployment rates of sensors and strike platforms is evaluated.

All of the models in the CAPE family, except Geo CAPE, treat geography as range bands from the FLOT. Sensors and targets are allocated to range bands. This minimizes input data requirements at the price of less accuracy.

Geo CAPE models terrain by quarter degree cells. Targets are allocated to cells, terrain masking is calculated by cell, and actual aircraft tracks are input. Targets are automatically moved by the program based on their type, the terrain, and phase strategy. This cellular automata technique eliminates scripting requirements. Geo CAPE calculates both the true target position and the sensed position. Differences are used to calculate a dynamic battlespace awareness value. Geo CAPE uses Dynamic CAPE techniques to calculate target, sensor, and strike platform attrition.

5.2 Spreadsheet Models

The SR&C group developed two supplemental tools to complement the CAPE assessments - an operational assessment tool and a post-processing tool. Each tool is discussed below.

5.2.1 Operational Assessment Tool

This Excel-based tool uses a scenario generated database in varying environments, so that with identical force laydowns the impact on the C4ISR mix could be examined in varying terrain and size of the AOI. The CAPE use of real-world operational databases, with CCDs modeled to reflect different capabilities of opposing forces operating in their respective terrain and environment, occasionally clouded results of assessments in the two MRC environments. This made it difficult to determine whether the performance of a C4ISR mix was due

[5] All of the CAPE models have processing, exploitation and dissemination modules, but at a higher level of aggregation than is found in the PEDS CAPE model.

to environment or because of the opponent and the force laydown.

The red database for the supplemental tool was built along the lines of CSEEA forces with 13 operational target categories. This allowed the results to be communicated in a more meaningful context than that allowed by the DAWMS target categories. Enemy targets were sized along troop/company/battery structures, so that results of strike engagements could be modeled against a single-sized target set. The supplemental tool included the close battle and deep sensors. In the close region, the supplemental tool included Unattended Ground Sensors (UGS) and observation helicopters/aircraft.

One of the outputs derived from the supplemental model measured the impact on lethality as a function of the performance of the C4ISR mix. The C4ISR mix performance variable correlated the percentage of critical targets that the mix identified through random collections; critical targets identified by precision SIGINT and cued for tracking to MTI; and situation awareness (calculated as the percentage of area coverage and area collections compared to the enemy area and target population, divided by the time of the decision cycle at the CJTF headquarters (assumed to be 24 hours)).

CAPE and the operational assessment tool complemented each other in that they considered different approaches to modeling sensor collections, communications and downlinking, point and area coverage, processing and exploitation. Despite some differences in their modeling approaches, the resulting assessments of mix performance showed very little difference thus providing a low-level validation of the conclusions that SR&C derived from the CAPE models.

5.2.2 Post-Processing Tool

This Excel-based tool consists of a set of macros which reads CAPE output files and automatically generates tables and graphs to support post-modeling analysis. First and foremost, the tool extracts the targets at risk MOE for various combinations of country, phase, OPTEMPO, range band, and target category. As part of these computations, the five measures of performance selected for the analysis are also computed and displayed graphically in a waterfall chart (an example is discussed in the following section). The waterfall charts proved very useful in analyzing (and briefing) results. This tool proved to be invaluable in analyzing the mountain of results produced by a single CAPE run as it reduced the post-processing time for those runs by more than a factor of 10.

The post-processing tool also permits the analyst to express output results in terms of operational target categories, such as tank columns, surface-to-air missile (SAM) sites, and C2 headquarters, instead of the more abstract DAWMS target categories used by the Deep CAPE model. This is accomplished by mapping the operational and DAWMS target categories into each other probabilistically.

6. Analysis

Time and resource constraints, coupled with the limited availability of good off-the-shelf analysis tools, led us to focus on the mission areas corresponding to the force mix studies, while developing an infrastructure for analysis that would support a wide variety of missions and circumstances. Since the JSEAD and TAMD force mix studies were not as far along as DAWMS and CSEEA, and since the desktop tools do not lend themselves to the theater air and missile defense mission, the analyses discussed in this report focus primarily on the Deep Attack and the Close Battle missions. Some JSEAD excursions were conducted..

Our plan was to assess the effectiveness of alternative C4ISR mixes. The goal is to make these assessments in the context of a specific scenario, but to vary the conditions over a broad range in an attempt to span the scenario space of interest.

Our assessments focused on the contributions of C4ISR systems in terms of providing information to decision makers. Assessments were taken down to the warfighter as far as possible without confounding the contributions of C4ISR with weapons, tactics, training, etc. The primary measure of effectiveness was targets at risk.

6.1 Baseline Run Descriptions

6.1.1 Portfolios of C4ISR Systems

Our intent was to use as the 'baseline' C4ISR portfolios those C4ISR systems that are presently in the DoD inventory for the 1998 portfolio, and those in the inventory and expected to be operational by 2006 as the 2006 portfolio. . Although this sounds rather straight forward, we quickly discovered that there are significant differences of opinion as to what C4ISR systems should be included. For the 2006 portfolios, we considered the C4ISR mix used in the DAWMS study, the C4ISR mix recommended by the Defense Airborne Reconnaissance Office (DARO), and a C4ISR mix recommended by CMA. After considerable discussion with all the involved parties, we decided that DARO would be the primary source of data for the 1998 baseline. *Table 1* indicates which systems were represented in the portfolios used in the analyses for the Deep Strike mission. The actual numbers of systems are sensitive and therefore are not included.

Sensors	1998	2006 DARO	2006-CMA
U2	X	X	0
Global Hawk	0	0	X
Dark Star	0	0	X
Predator	X	X	X
ATARS	X	X	X
Outrider	X	X	X
SOF/LRSU	X	X	X
JSTARS	X	X	X
UAV MTI	0	0	X

Table 1. C4ISR Portfolios

6.1.2 Scenarios

The scenarios were selected to maintain consistency with the ongoing force mix studies (primarily DAWMS and CSEEA). These studies used a 2-MRC scenario (SWA and NEA) that was originally developed to support the Nimble Vision/Nimble Dancer Exercises. In addition to using the 2-MRC scenario, we decided to modify these to include a 1-MRC scenario for SWA and NEA. The total number of C4ISR systems available in each time frame and in each portfolio was held constant for both the 1-MRC and 2-MRC cases. We also considered a 'generic scenario' to explore the impact of changes to various parameters of interest on the effectiveness of the candidate C4ISR portfolios.

6.1.3 Systems Characteristics

Where possible, system characteristics data were obtained from DARO. The majority of key C4ISR system characteristics data were in fact available from DARO. However, there were numerous other parameters required by the CAPE models that were not available. In those instances, subject matter experts from the CMA team (government and non-government) were consulted. When we felt that the data were extremely soft, excursions were run to examine the sensitivity of results (especially between portfolios) to changes in those parameters. The results of some of those excursions are discussed later in this section.

6.1.4 Target Laydown

The target laydown for the SR&C analyses was identical to the DAWMS laydown (see *Table 2*). All targets were arrayed in range bands according to their distance from the FLOT. There were four range bands defined as follows: (1) 0-40 kilometers (km); (2) 40-150 km; (3) 150-343 km; and (4) >343 km. Also, in accordance with the DAWMS methodology targets were placed into one of seven target categories:

Category	Name	Note
1	Fixed Large	
2	Fixed Small	
3	Long Dwell Large	Dwell > 1 hour
4	Long Dwell Small	Dwell > 1 hour
5	Short Intercept	Dwell < 1 hour
6	Mobile Column Long	> 10 vehicles
7	Mobile Column Short	< 10 vehicles

Table 2. Target Categories

Targets in categories 3 through 7 have tactical mobility. Each target moves some of the time and dwells some of the time, thus offering the possibility for detection by all overhead sensors. Each target type has a cycle time consisting of a dwell period plus a movement period. For instance, a typical cycle might be to dwell for 8 hours and to move for 2 hours.

The CSEEA study placed targets into one of 13 operational categories. A mapping between these 13 categories and the seven DAWMS categories was created to facilitate comparison of results. However, an analysis of the close battle was not completed due to funding and time constraints.

6.1.5 Phases

Two phases were defined for the analyses:

1. Phase 1 is defined as the time from initial deployment of C4ISR assets to an MRC until full-up deployment of those assets is achieved. During Phase 1, it was assumed that JSEAD had not been accomplished. Hence, the majority of C4ISR platforms, if available, were employed in a standoff mode. This period is also referred to as the “pre-JSEAD” phase of the deployment. It corresponds to “D+Days”.
2. Phase 2 corresponds to full-up deployment. All assigned C4ISR assets are assumed to be available during Phase 2. Furthermore, Phase 2 assumes that enemy air defenses have been suppressed, so that all but the really high value overhead sensors can operate in overflight mode.

6.1.6 OPTEMPO

Three levels of opposing force operations tempo (OPTEMPO) were modeled. Low OPTEMPO corresponds to defensive operations. In low OPTEMPO it is assumed that many units “go to ground” and movements are minimized. Medium OPTEMPO corresponds to movement-to-contact type operations. At this level it is assumed that the majority of units move periodically (an average move frequency distribution was used for modeling purposes). High OPTEMPO corresponds to offensive operations. At this level units move frequently and second echelon and support units move greater distances on the average. *Table 4* shows the general relationship between Red operations and the OPTEMPO levels.

Red OPTEMPO	Red Operation
Low	Defensive
Medium	Move to contact
High	Offensive

Table 4. Red OPTEMPO

6.1.7 Sensor-to-Shooter Strings

A total of 22 sensor-to-shooter strings were defined for *Deep CAPE*. Five of these strings represented SIGINT cues to other collection platforms. For each sensor-to-shooter string, the times associated with each component (C2, communications, processing, exploitation, dissemination) were gathered from published reports and exercise results. These times were then input to *CAPE* where they were incorporated into the appropriate queue and string. *Figure 2* shows a JSTARS string (T_4 represents the missile flyout time).

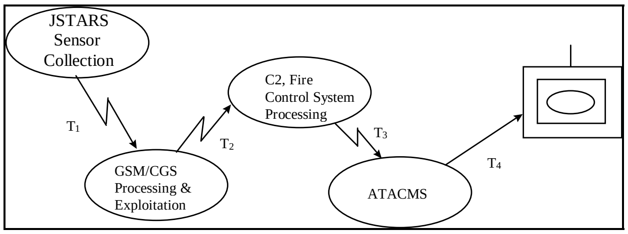

Figure 2. JSTARS String

6.1.8 Shooters

A total of five types of shooters were identified for deep attack operations. For each type of shooter, one or more representative munitions was also identified (see *Table 5*). These munitions were selected based on TLE requirements for targeting and the range of the weapon. For each shooter/munitions pairing, a TLE and time required to successfully engage a particular target type are provided. These values were then used to determine whether a target could be held at risk by a specific shooter/munitions combination.

Shooter	Munitions
ATACMS	APAM/BAT
A/C on Station	APAM/SFW/Unitary/APAM
Mod ATO A/C	APAM/SFW/Unitary
ATO A/C	Unitary/SFW/APAM
ATO TLAM	TLAM

Table 5. Shooter-Munitions Combinations

6.1.9 Waterfall Charts

The display mechanism chosen to present the majority of results consists of a series of bar charts referred to as waterfall charts due to the descending nature of the bars on each chart. Each waterfall chart contains seven groups of bars which represent the C4ISR measures deemed important for comparing results. Each measure is discussed below.

Target population -- the total number of targets present for the particular scenario, phase, and range band.

Operational coverage -- the maximum number of target detections by all sensors that would be possible per hour, given weather, terrain, and foliage degrades (also referred to as *accessible* targets).

Capacity -- the number of spot resolution images and MTI reports that can be processed for downlinking (per hour) by all sensors.

Collections – the total number of accessible targets (per hour) degraded by cover, concealment and deception (CCD).

Downlink -- the number of collections that can be downlinked to ground processing stations (per hour).

Exploitation -- the number of downlinked targets (per hour) which can be exploited, processed through the command and control system, and transmitted to the shooter with sufficient time remaining before the target changes states[6].

Targets at Risk-- the number of exploited targets (per hour) that also meet TLE requirements for one or more shooter-munitions combinations. That is, there is at least one weapon with sufficient range and footprint that it could put iron on target before the target changes status.

6.2 Baseline Results

Baseline results consist of all combinations of C4ISR portfolio (1998 and 2006); MRC (1 or 2);

[6] A state change corresponds to a change from dwelling to moving or from moving to dwelling.

country (SWA and NEA); phase (partial and full deployment); and, OPTEMPO (low, medium, and high). For each combination, results were analyzed by range band and target category, and then by target category aggregated over range bands. *Figure 2* depicts a typical waterfall graph for the 1-MRC cases. The graph is a comparison of the 1998 Mix, the 2006 Mix, and the CMA Recommended Mix. Some of the baseline results are summarized below.

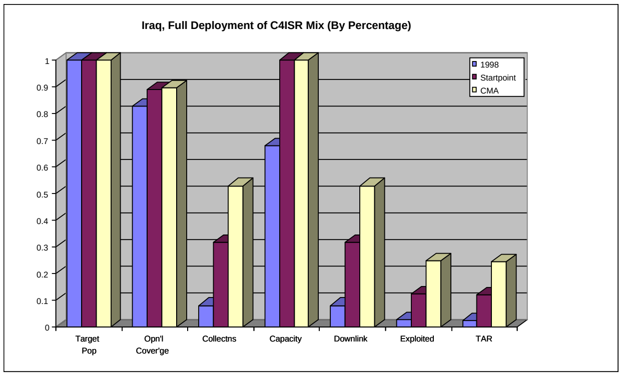

Figure 2. Waterfall Graph for 1-MRC Baseline Case

6.2.1 Mix Comparisons (2006)

Coverage. Both 2006 mixes could provide adequate coverage of the operational area. The CMA mix was more capable owing to (1) the greater flexibility afforded by the larger number of small satellites, (2) the ability to take more risk (overfly enemy territory) with UAVs during the early deployment, and (3) the self deployment capability of the Global Hawk.

Collections. Mix capabilities to collect targeting information were proportional to area coverage.

Processing and Exploitation. Global Hawk's proposed reach back processing conferred an advantage in the early deployment, so that processing assets and analysts would not have to compete for deployment lift. The UAV's capability to downlink finer resolution images has the potential to reduce exploitation time, lower analyst requirements and sensor-to-shooter time lines.

Targets at Risk. Since JSTARS is the principal targeting asset during the halt the invasion phase, and since Link 16 was assumed to exist for both mixes, there was limited difference in attacks on moving targets. The CMA mix performed better primarily because it had six additional HAE MTI platforms incorporated in the mix. The UAVs had better sensor-to-shooter time lines than the U2, thereby improving the numbers of dwell targets put at risk by the CMA portfolio.

6.2.2 1-MRC Results

Phase 1. At C+ days, the C4ISR systems could hold many more targets at risk than the decision maker would have available weapons to engage. We would expect this ratio between targets and weapons would decline as the enemy suffered losses, but would temporarily increase as the full capabilities of C4ISR were deployed faster than the full array of air wings, carrier battle groups, MEFs, and Army corps could arrive and be operationally employed.

Phase 2. Fully deployed C4ISR mixes met targeting and information requirements associated with the mission to halt conventional enemy attacks in an MRC environment.

6.2.3 2-MRC Results

Owing to the numerical reduction in high altitude air breathing assets, a large SWA-like operational area presented more challenges to the C4ISR system than a smaller operational area, despite the greater terrain relief in the smaller area. The overall impact on the reduction in assets was mitigated when overflight capabilities could be achieved. As noted, C4ISR mix numbers associated with early deployment were nearly as effective in locating deep targets when operating under overflight conditions as they were when operating with full deployment numbers.

6.2.4 Caveats

The concept of operations for many of these sensors is still evolving. For example, the way that commanders will utilize Predator, Dark Star, Outrider and Global Hawk is yet to be worked out. How will they use tactical UAVs in conjunction with rotary winged reconnaissance? In performing the analyses reported above, we applied the capabilities of the sensors and the operational concepts as best we could determine. The CAPE models allow one to easily explore new operational concepts for the sensors and platforms, e.g., to cue precision SIGINT to MTI.

One should also understand that the TAR MOE does not imply that one could actually attack all of the targets put at risk. For example, for those enemy targets located within 350 km of the FLOT, the ATACMS was the most effective weapon for putting targets at risk. However, there are relatively few ATACMS missiles available to the commander at any given time. Moreover, the targets may range in size from platoon to battalion-sized elements. Thus, multiple ATACMS would be required to successfully engage a single battalion-sized target.

6.3 Excursions

In addition to the baseline runs, several excursions were run to examine issues that arose in previous analysis runs, and to explore issues recommended by Track 1, or issues suggested through the campaign mining. Excursions were conducted to assess the following issues:

- Impact of improved communications, especially with regard to the C2 links to the weapons platforms.
- Impact of processing and exploitation reach back capabilities.
- Impact of the temporary elimination of the JSTARS MTI platform, resulting either from increased air activity at day one of the operation, to consideration of development of enemy capabilities to conduct successful IW/EW against this platform for brief periods of time.
- Increased number of analysts compared to enhanced resolution of area and point imagery products.
- Comparison of mix performance based on the number of analysts being dedicated to support BDA.
- Impact of investment in better weapons/munitions with constant C4ISR as compared to investment in better C4ISR and constant weapons/munitions.

Excursions were conducted using both CAPE and the Operational Assessment Tool. Only a representative sampling of excursion results for the CAPE model are discussed below.

6.3.1 Offensive Operations

Offensive operations (Blue counterattack phase) were assumed to be conducted with a fully deployed C4ISR mix (in a single MRC or dual MRC environment). Overflight capabilities were essential to support U.S. ground offensive operations, so that critical enemy targets could be identified and attacked throughout the depth of the operational space. Without overflight, U.S. offensive operations would not be supported with sufficient knowledge concerning location, status, and intent of deep enemy forces, and might not be able to synchronize optimal attacks against these forces in support of the campaign plan. It was assumed that offensive ground operations were not initiated until overflight capabilities were achieved.

6.3.2 MTI with Link 16

MTI with Link 16 provided the greatest targeting capability. Enemy targets could evade track only if they managed to “hide” behind terrain relief or practiced deception tactics of altering speeds to a near stop condition (making them vulnerable to imagery targeting, and opening the feasibility for considering cueing MTI to imagery so that an enemy cannot practice altered speeds and escape detection). Under optimal conditions like the terrain in Southwest Asia, MTI with Link 16 could hold track on 90% of detected targets until they could be attacked. In the 1998 baseline assessments, this capability ranged from 85% in the close battle area (where there was more limited time for the weapons system to execute the attack) to approximately 80% when targets in the intermediate (40-150 Km) range were attacked. Of course, the total number at risk was much lower, owing to the larger numbers of JSTARS in the 2006 mixes. Excursions that examined mix capabilities in the absence of a JSTARS (assuming that enemy air operations had forced the aircraft to leave orbit temporarily) demonstrated the predictable results that virtually no moving targets beyond the immediate detection of close battle sensors could be held at risk.

This excursion produced even more dramatic results when it was coupled to increased enemy OPTEMPO, assuming the enemy could exploit those brief periods when JSTARS might not be effective by accelerating their operational tempo. The presence of a HAE UAV MTI in the CMA’s recommended mix mitigated the impact of this temporary loss of JSTARS.

During US ground offensive operations, owing to reduced enemy movement, MTI held relatively fewer targets at risk. However, those MTI tracked targets would represent the enemy’s tactical and operational mobile reserves, so that the absolute value of MTI remained high during periods of reduced enemy movement. Indeed, MTI managed to detect and hold track on the entire moving target population with considerable spare capacity. These results deserve greater examination, because they would suggest that in a dual MRC the greatest contribution of MTI is in the “halt the attack” phase, so that once this was achieved in the first MRC, most of the MTI assets could be deployed to the second MRC.

6.3.3 Precision SIGINT

A similar phenomenon held true during ground offensive operations with the precision SIGINT cueing CONOPS. In a defensive posture fewer tank and mechanized command nodes were transmitting; however, when they did transmit, cueing improved MTI capabilities to track movement of these critical mechanized reserve assets. There was also the assumption that ground operations would not begin until the enemy’s high altitude mobile air defense missile batteries had been neutralized, so that relatively fewer critical SIGINT targets remained for detection and cueing at the time offensive ground operations commenced.

6.3.4 Reach-Back

Reach-back processing and exploitation optimized mix capabilities during the early deployment period before large numbers of analysts and processing equipment might be deployed. If an early overflight capability were achieved, then reach-back would also be necessary to process and exploit the additional sensor collections. Area and point imagery with finer resolution accelerated processing time, with an overall improved tradeoff in mix performance (even when downlinking this enhanced resolution used more of the sensor platform’s downlink capacity).

6.3.5 Overflight Scenarios

An early deployed C4ISR mix produced nearly identical results as a fully deployed mix if the C4ISR assets could overfly the operational area. Overflight capabilities were assumed to exist when the opposing high altitude missile air defenses were neutralized. These results applied primarily to those deeper range bands assessed by CAPE. In the supplemental model, full deployment greatly increased results in the close range band, as more Outrider, Tac Recce, and OH-58s could increase target detection rates. Until overflight could be achieved, high altitude platforms were more effective in observing the enemy's operational space than medium altitude platforms. This capability was particularly important in those areas with extensive terrain relief. The Global Hawk MTI platform, when using a CONOPS of precision SIGINT cueing, provided a greater capability to track critical targets deep in the enemy's operational area. With overflight, the C4ISR system could greatly extend its coverage of the total operational area. As overflight capabilities enabled the system to cover more area, more analysts were needed to exploit the greater number of processed ISR products. Achieving an overflight capability early in the campaign, without the capability to use this increased coverage by having sufficient processing and exploitation available, undermined the potential of this capability.

6.3.6 Comparison of Improvement to C4ISR with Improvements to Lethality

All the evaluated C4ISR mixes could detect, process, and exploit more enemy targets than US forces would have weapons available to attack, especially in a limited warning, halt an invasion scenario. Therefore, it would seem that investment in improved weapons systems lethality would be more effective than improved C4ISR. We used the operational assessment tool to examine this hypothesis, comparing the CMA mix with its faster processing and communications, against the DARO 2006 mix, with both improved and 1998 communications. The number of available weapons platforms remained constant against a common threat laydown. Weapons lethality for the other mix was assessed using 0%, 25%, and 50% improvements compared to the CMA mix with a 0% increased lethality. The results suggest that speed, rather than enhanced lethality, kills. The CMA mix, with its combination of faster ISR processing and exploitation, and data transmission rates through the command and control systems, provided targeting information to the weapons much faster. This greater speed of sensor-to-shooter information increased the probability of weapons engagement, striking a dwelling target before it could leave its location or a moving target before it could break MTI track.

Weapons supported by the CMA mix routinely engaged 7-14% more enemy targets with the several hundred strike sorties available in a 24-hour period. For the other mixes, this percentage represents increased lethality munitions hitting dirt or aborting because the supporting C4ISR was not sufficiently responsive to enable the weapon to attack the target in its detected location. In all scenarios the CMA mix outperformed mixes supported by a 25% increased lethality, and were very close in performance with mixes supported by 50% increased lethality.

7. Summary

The above results support the following observations:

- Improved sensor collection and more rapid exploitation can significantly increase the number of targets that can be held at risk.

- Improved sensor capabilities associated with the MAE UAV give the deployed commander greater capabilities without having to bring as many support assets into theater.

- Improved data transmission rates between C2 systems and weapons significantly increase the number of deep targets that can be held at risk. Here the CMA's use of an HAE MTI gave the commander deep tracking capabilities with less interference owing to terrain relief and clutter.

- The enhanced CMA capabilities will yield fertile ground for adapting tactics, techniques, and procedures to exploit the full potential of these capabilities. For example, the CMA mix explored the concept of cueing precision SIGINT targets to MTI, with the result that critical targets at risk usually increased several-fold.

The MRC threats that we face have a limited ability to field large numbers of well trained formations outfitted with modernized equipment. As long as this paradigm remains true, then the ability to identify, detect, and hold at risk a high proportion of critical targets will give the warfighting advantage to the JTF.