Methodology for Determining EW JMEM

By Dave MacEslin

Editorial Abstract: *Mr. MacEslin examines a detailed methodology to establish precise measures of effectiveness for electronic warfare operations. He compares EW planning and weapons selection with current kinetic examples, and proposes standard definitions, quantification methods, and measurement of desired effects.*

Author's Note: *As part of the overall Electronic Warfare (EW) Joint Munitions Effectiveness Manual (JMEM) effort, I present the following paper as an ongoing work in progress on a possible methodology to develop an EW JMEM for the EW JMEM Working Group. It is meant as a starting point, and not the final solution. Linus Torvald (developer of the Linux computer operating system) characterizes it this way: "Given enough eyeballs, all bugs are shallow." I look forward to receiving any thoughts and comments you may have on this subject.*

Defining Electronic Attack Effects Expectancy

We must first define the term EA, effects expectancy (EE_{EA}), before starting to develop a mathematical model to predict effectiveness of an electronic attack. The proposed definition:

> ***Electronic Attack effects expectancy defines the probability that a platform with the required system(s) and technique(s) can, within acceptable limits, reach the execute point and produce the desired effect on an EA target.***

Elements of this definition include several items of interest:

- For the purpose of EE_{EA}, an EA target is the range of sensors, networks, and receivers that can be affected for the required duration by a single weapon that produces the desired effect specified in the commander's objectives. Since it is rare during a mission for a jamming platform to jam a single receiver, and EA effects generally are spread over a large geographic area, the problem is not limited to affecting a single receiver.
- The definition does not account for adversary self-defense mechanisms and techniques (e.g., IADs, harbor defenses, etc.) other than those built into the target system, such as electronic protect measures (EP).
- Acceptable limits can be a percentage of time of signal on target and/or jamming to signal ratio, or any number of criteria. Limits will vary depending on the type of system being affected.

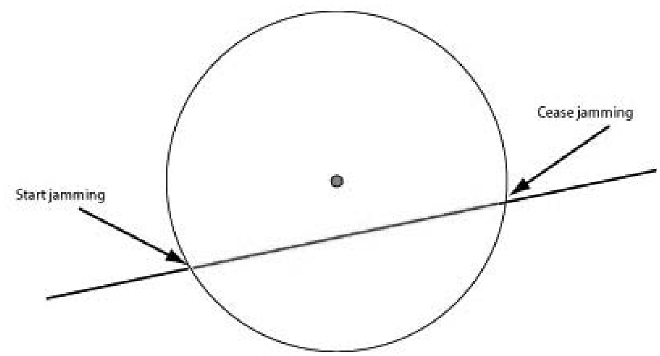

Figure 1

In addition, we need to consider the varying degrees to which we can achieve effects. The difficulty in determining nonkinetic effects expectancy lies in the definition of "effects." We often see words such as "deny," "degrade," or "disrupt" within the commander's objectives, guidance, and intent. By themselves, these words are insufficient; they must be defined against parameters in order to plan a mission. To simply deny communications between two stations is not enough: we need to know for what purpose, to what level, and for how long. Denial implies variables that must be clearly specified and laid out, so that we can employ correct jamming techniques and determine predictions of effectiveness.

Just as in kinetic warfare, we can characterize many EA effects using three primary variables:

- Scope – description of specific target or target set (Surface-to-Air Missile site or entire Integrated Air Defense System).
- Amount – the extent of the effect. Effects are either: partial, represented by a percentage of total capacity, or complete; i.e., total.
- Time – the duration of the effect. Effects are either temporary or long-term; i.e., permanent.

This simple construct leads to a more correct, hierarchical effects definition based on the overarching function of denial, in which to deny is to cause reduction, restriction, or refusal of target operations (regardless of time or amount). Significantly, this acknowledges that degrade, disrupt, and destroy are all

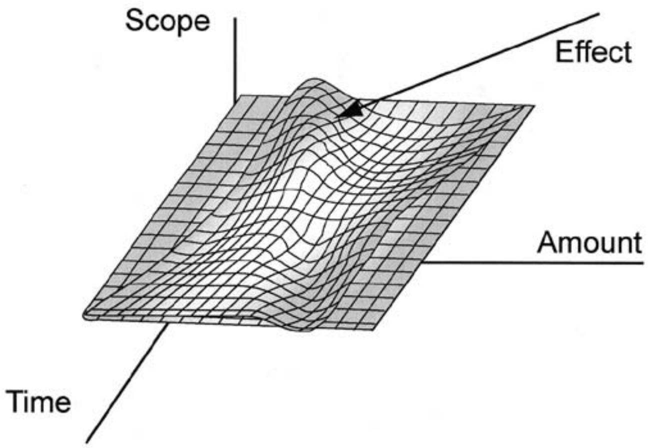

Figure 2

different forms of denial. Disruption introduces the time aspect of denial (i.e., less than permanent), and degradation introduces the amount, or level of denial (i.e., less than total). Destruction is the special case that includes the maximum time and maximum amount of denial.

To illustrate by use of kinetic example, consider the tactical order to deny the use of a bridge to the enemy:

• This could be done temporarily, by disrupting traffic flow by attacking and disabling bridge traffic to block the bridge.

• This could be done partially, by degrading the bridge structure so that it will support only light vehicles and foot traffic.

• Destroying the bridge could also do this.

Each of these can be an effective form of denial. These definitions also allow useful combinations of effects, whereby a target can be both disrupted and degraded (e.g., "the flow of traffic on the bridge will be completely blocked for three hours, and thereafter limited to vehicles under 2 tons"). Since the goals of most EW actions are also effects-based, an EW mission requires us to describe effects in unambiguous terms.

Quantitatively, it should be possible to express denial (D) as a function of scope (s), amount (a), and time (t), as D(s,a,t). Defining effects in this manner clarifies to the planning staff that they must consider and specify, as needed, each of the parameters of the function, and derive each directly from the commander's objective. As the amount (a) or level approaches 100% and time (t) approaches infinity, we can accomplish destruction. Time can be ASAP for a specified period of time, a start time with a specific duration, or a start and stop time. Since destruction is an effects-based concept that will vary by mission, Information Operations (IO) mission planners must decide both the amount and duration required to achieve destruction. Note this is no different from the kinetic example, since even destruction of a bridge is not permanent; it is only "effectively permanent," based on the timeframe of the campaign, and the time and resources required to rebuild it.

Some examples of IO mission tasking using this construct:

• Degrade throughput on all channels of a microwave communications tower at specified GPS address by 75%, beginning at 0630 for 3 hours.

• Disrupt Internet service at a named cybercafe from 2130 until 2145 for the next 3 days.

• Destroy the 80GB hard drive at given IP address tonight after 2300, but before 0430.

Note that each denial effect has a scope, amount, and time either specifically stated or unambiguously implied. Additionally, only one of these effects can be considered 'damage.' Degrade and disrupt may in some cases be synonymous terms, as a jamming signal is either on or off, and the degradation would be total disruption.

Damage Expectancy Criteria

Three major components which determine damage expectancy within the kinetic world should also apply in any nonkinetic effects expectancy model:

• Target vulnerability – an assessment of a target's loss of capability when impacted by a weapons damage mechanism

• Weapons characteristics – quantification of damage producing mechanisms and reliability of munitions

• Delivery accuracy – a measure of weapon system's capability to place munitions on targets.

A target's vulnerability is an exploitable weakness of the target receiver. A target's vulnerability manifests itself in terms of the parameters of scope, amount, and time. Some of the questions which determine if an EW target has an exploitable weakness must include:

• Are the components of the target that must be affected hardened or shielded? Which of the receiver's critical components must be defeated to satisfy objectives?

• Regarding countermeasures, is the receiver exploitable or do they have methods to determine jamming and TTP to decrease effectiveness? How well are they trained in using the equipment and in recognizing jamming?

• Do we have access? Can we reach the point at which we can produce effects? (This is simply a time and distance problem.) Can our weapon reach the point at which it can produce desired effects, or is it too far from where we must execute our mission?

This is only a starting point. We have to develop a target vulnerability manual listing all the vulnerabilities we must know, in order to best target a receiver. Some of the items listed above will not be in a vulnerability manual, but must still be part of our JMEM determination.

Weapon characteristics are the specific details of the chosen weapon, such as the AN/USQ-146 Rubicon or AN/ALQ-99 Tactical Jamming System. Weapon characteristics manifest themselves in terms of amount and time, and are independent of scope. Kinetic JMEMs do not attempt to dictate—or even recommend—tactics, nor should we. Some considerations in determining EA weapon characteristics include:

• Frequency, power, polarization, gain

• The percentage of time the jammer can maintain a desired signal on the target receiver during the mission

• The failure rate of the chosen weapon system

Delivery accuracy is a consideration in terms of scope, amount, and time.

• Can the jamming signal be maintained on target receiver for the duration of mission?

• During the time when jamming is executed, how much of the time is the desired signal on target receiver?

• Nulls created by the delivery platform

• Environmental conditions

• How many target receivers are we trying to affect during the mission (commutation)?

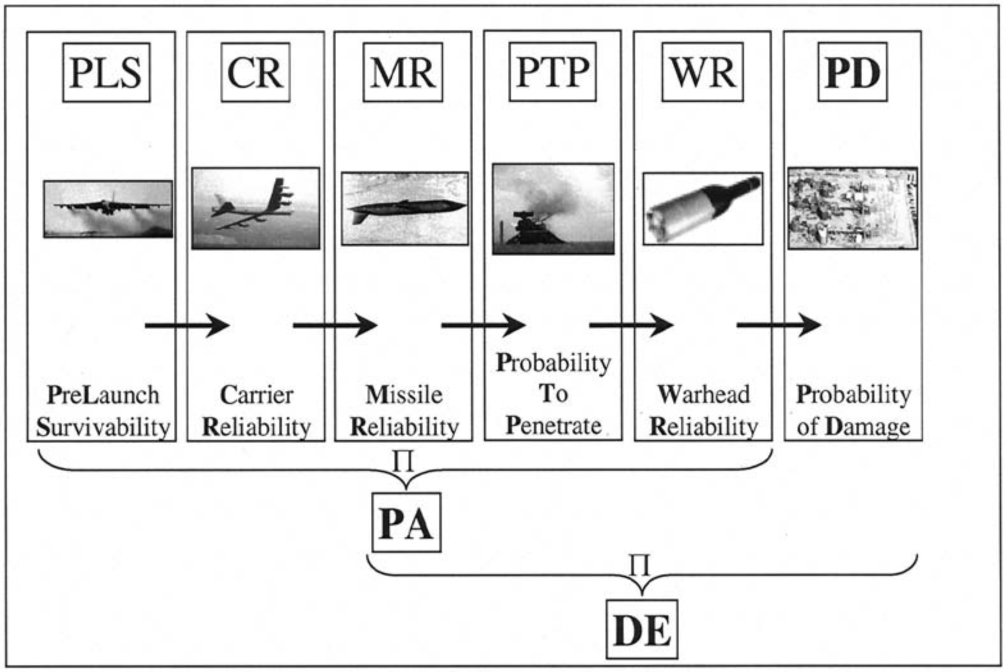

Figure 3. Kinetic Planning Factors

Effects Expectancy Construct

Based on the above discussion, our model must be stated in terms of scope, amount, and time. We must consider target vulnerability, weapon characteristics, and delivery accuracy in our considerations.

In Mr. Bud Whiteman's paper, "A Framework for CNA Planning," dated 25 May 2005, the author develops a CNA planning paradigm based on the kinetic planning paradigm, which we will also use as a basis for developing EE_{EA}.

Figure 3 shows an air-launched cruise missile mission, decomposed into phases, with each phase being evaluated for probability of succeeding.

Multiplying each factor of the decomposition shown determines the overall damage expectancy (DE). Because inherent dependencies exist between phases, each factor in the sequence depends on the prior phases being successfully completed. We can then multiply to determine composite probabilities, in accordance with the multiplicative law of probability. Although some dependencies may remain, even with this conditioning, the approach has proved useful in planning kinetic weapon employments.

Note even the definition of each factor depends on the successful completion of the previous phase. This allows multiplication of each factor to produce an overall probability of success (see standard statistical methods of multiplicative law of probability and the method of event-composition). Even with this technique, interdependencies between factors remain. For example, a missile performance degradation (e.g., reduced air speed, compromised stealth, or reduced agility) falls in the missile reliability (MR) phase - where missile performance is considered - but could affect penetration where performance is assumed to be nominal in estimating probability to penetrate (PTP). Similarly, a near miss during a prelaunch attack could affect carrier reliability (CR). These recognized inconsistencies are considered minor compared to major considerations of the process, and other known inaccuracies in their estimates (e.g., simulation assumptions).

In many cases, these factors are further subdivided into sub-phases. This allows different organizations with cognizance over different sub-phases, data from different sources, and different models to operate with a degree of independence and contribute to the overall evaluation. Separate terms allow planners to identify component strengths and weaknesses of weapons systems.

We generally report factors to the warfighter, store them in a database for use in course of action (COA) selection, and later in specific mission planning. The independent component nature of the framework allows some mixing and matching of factors from different systems and scenarios. For example, the prelaunch survivability (PLS) and CR for a given aircraft may be the same, whether the aircraft is delivering cruise missiles, gravity bombs, or an electronic attack. Likewise, the warhead reliability (WR) for a bomb that can be delivered by different aircraft types may still have the same WR. On the other hand, there may be substantial differences even within the same weapon subsystem that may require different factor values. For example, the same airframe at different bases will have different PLSs. Some warheads may have different modifications and alterations in place, and require different WRs. In these cases, as with sortie PTPs, the initial plan would include a generic factor value, then when assignments are made, the plan would be evaluated with actual factors.

Empirical and theoretical data to support modern kinetic planning has been collected and analyzed for decades. Even so, kinetic effectiveness estimates still require engineering estimates, and contain other sources of significant uncertainty. We can expect uncertainties of 25% in the probabilities described above. Through the decades, planners and decisionmakers have become comfortable with kinetic models and supporting data, so estimated uncertainty is almost always omitted in kinetic planning briefings. EE_{EA} does not have the luxury of decades of models, support data, and comfort; therefore we include uncertainty in our calculations.

EA Planning Factors

Table 1 compares and contrasts the kinetic paradigm with one that might be useable for EE_{EA}

Table 1

Kinetic Phase	*EA Phase*
Prelaunch survivability	Same
Carrier reliability	Transport reliability
Missile reliability	Equipment reliability
Probablity to penetrate	Same
Warhead reliability	Signal reliability
Probability of arrival	Same
Probability of Damage	Probability of effects

PLS is the probability that the transport vehicle survives enemy action to be available for mission execution. This factor does not include any reliability of the vehicle or support system. Our evaluation of the enemy's intent, capabilities, and effectiveness (enemy's DE against the transport) determines the value of PLS. It applies to all platforms, although the data may be currently available only for some aircraft. We will account for this as we develop effects expectancy for electronic protect, though it should be a known factor from the kinetic world for many aviation platforms.

Transport reliability (TR) is a measurement of the reliability of the platform that transports jamming equipment from a base of operations to the point where jamming is required (aircraft leaves deck, tank leaves staging area, etc.), and applies to all platforms from the time of mission execution. This may be a percentage of the time remaining before the expected failure of equipment based on historical mean time between failure data. This factor should also already be known from the kinetic world for many aviation platforms.

PTP is the probability that a reliable transport can successfully penetrate enemy defenses and get to the desired execute point. It is primarily a function of the enemy's ability to detect, engage, and successfully target the transport vehicle. This value should not be specific to a particular mission. It consists of generalizations—for example, Country X has previously shot at aircraft 56% of the time. This factor should already be known form the kinetic world for many aviation platforms.

Equipment reliability (ER) is a measurement of the reliability of the jamming equipment (transmitter, transmission line (cable or waveguide) and antennae). The transmitter portion of this should include power generation reliability. This data should be available from the owning systems command, program office, or resource sponsor.

Signal reliability is a function of the enemy ability to detect and counter jamming, and the jammer's capability to maintain the desired signal on target for the required timeframe. This section should consider the physics of the radar equation.

The product of terms PLS, TR, PTP, and ER is referred to as probability of arrival (PA), the cumulative probability that the jammer will be delivered to a position near the aim point and be able to energize the jamming system.

The IO and special effects (FX) working groups have defined probability of effect as the probability (chance) of a specific functional or behavioral impact on a target, given an

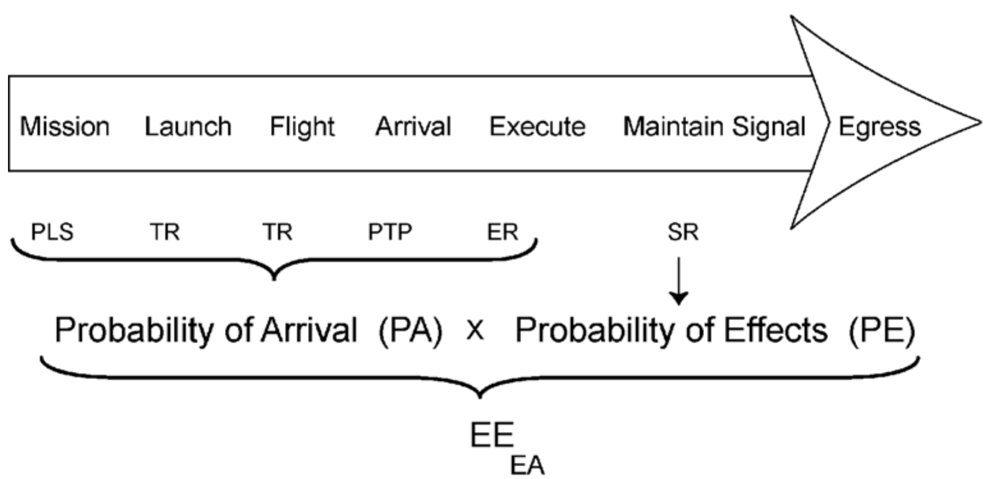

Figure 4

		Table 2		
PLS Delivery accuracy	TR Delivery accuracy	PTP Target vulnerability	ER Weapon characteristics and target vulnerability	SR Weapon characteristics and target vulnerability and delivery accuracy

action. Probability of effect (PE) must include the functionality of signal reliability (SR).

The product of PA and PE is equal to EE_{EA}. In mathematical terms:

$$EE_{EA} = PLS*TR*PTP*ER*SR$$

Figure 4 illustrates that the term egress is listed to complete the mission profile or time line, but per the proposed definition, once jamming has ceased the mission is considered accomplished; thus, egress is not an issue.

Mr.Whiteman's paper goes on to discuss the primary military objective (PMO), which I believe is still relevant to meeting a commanders objective, but not to an individual task. For example, if the commander's guidance was to disrupt all communications between PT A and PT B for 3 hours starting at 0600, 25 August [notice relationship to scope (PT A and PT B), amount (all), and time (3 hours with a start and stop time)], IO planners would have very specific guidance on what effect to achieve. Intelligence indicates that communications between PT A and PT B include HF radio, Internet chat, both cell and land line telephone. The IO planner must determine the product of effects expectancy against each individual communications method to determine the expected effectiveness against the primary military object (disrupt communications).

$$EE_{PMO} = EE_{EA}1 * EE_{EA}2 * EE_{EA}3 * EE_{CNA}$$

Notice the term EECNA inserted to take into account the use of the Internet chat to communicate between the two points. EEPMO is how we determine effects of multiple receivers on a single mission. We determine the product for each individual receiver and the product of all receivers combined. This term could just as easily be EEIO to account for all possible methods in which we may be using IO to achieve the commander's objectives.

To ensure we have met all the criteria of damage expectancy, and that each damage expectancy criteria is placed within the EE_{EA} construct, we should relate the above terms back to the previously mentioned damage expectancy criteria.

Terms of Reference or Lexicon

This list will grow over time. The intent is to have as few EW specific terms as possible. The desire is to have the lexicon be standard across IO and, hopefully, adaptable to the kinetic world as we increasingly move towards effects based operations.

The most important terms to quantify are the dreaded "D" words—deny, degrade, destroy, disrupt, deceive, and delay. The earlier discussion of deny in terms of scope, amount, and time answer this question, as long as we can convince our commanders to give very specific objectives, guidance, and intent.

The Way Ahead

Assuming that the discussions above are acceptable, we must now determine the way ahead. Recommended actions include:

1. Determine weaponeering methodology

(a) Break the damage expectancy criteria into very specific pieces, in order to determine what items support what portions of the EA planning factors.

(b) Determine interdependencies between damage expectancy criteria.

(c) Determine uncertainties in the EA planning factors.

2. Develop target vulnerability and weapons characteristics manuals.

3. Develop collateral damage methodology.

4. Develop weapons-target pairings manual/matrix.

References:

1. Schuh, Paul, USSTRATCOM, "A CNA Testing, Planning and Weaponeering Lexicon" version 0.9, dated 8 Jul 2005

2. Whiteman, Bud, USSTRATCOM J883, "A Framework for CNA Planning," dated 25 May 2005

3. Whitehouse, Stephen R. et al, Information Operations (IO) JMEM Concept Definition and Exploration Final Report, dated Oct 2003