A Scenario Selection Methodology Supporting Performance Analysis of Theater Ballistic Missile Defense Engagement Coordination Concepts

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Distributed weapons coordination describes an approach for efficiently responding to incoming raids through maximum use of available force resources. While this could be applied to a number of different mission areas, the primary focus today is on Theater Ballistic Missile Defense (TBMD), in which large raids and a diverse set of defending units are expected. Because of its highly complex nature, real-world experiments for this scenario are unlikely, indicating that efforts to understand which distributed weapons coordination concepts are most effective will be analytical in nature. These analyses depend heavily on the selection of scenarios that tax the abilities of TBMD resources to handle an incoming raid. APL has developed a methodology, described herein, based on a set of factors, including raid size, timing, locations of launch and impact points, and locations and capabilities of defending assets against each threat, to establish stressing TBMD scenarios for distributed weapons coordination analysis.

INTRODUCTION

In a world of proliferating, more accurate, longer-range threats like theater/tactical ballistic missiles (TBMs),[1] held by nations that are willing to use them and opposed by limited defensive capabilities, the defenders must intelligently use their assets to defeat these threats.[2] One approach proposed is the use of engagement coordination (EC), a means of determining which of several defending units will be chosen (a "preferred shooter") to engage each threat in a TBM raid. EC encompasses the methods, procedures, and processes used to preferentially select, schedule, and execute engagements when multiple weapon systems are capable of engaging threats. Selection among existing preferred shooters is based on the application of mutually established rules and criteria to the current, commonly understood tactical situation.

Short of experiencing a full raid, performance evaluations of different EC concepts will occur via analysis of a set of scenarios deemed as appropriate representations of the challenges that Theater Ballistic Missile Defense (TBMD) forces will encounter. (TBMD and National Missile Defense are now part of the overarching mission of Ballistic Missile Defense [BMD].) A scenario[3] consists of a setting (initial conditions), actors (TBM threats and

TBMD units) that carry out events (for TBM threats, attack on opposition forces or sites; for TBMD units, threat detection and assessment, weapon selection and engagement), and goals (for TBM threats, destruction of opposition locations; for TBMD units, the negation of a raid to a predefined level). In existing TBMD scenarios, threats are nonreactive and scripted as part of the initial conditions.

The challenge is to use scenarios that can demonstrate the conditions under which different EC concepts perform at different levels of success. Some of these scenarios may exist, although some may still require generation. Since analyses have limited resources, not all scenarios can be tested.

We contend that criteria that represent key features of useful scenarios can be established and used as part of a methodology to select viable candidates. These criteria are expressed in terms of features of each scenario's unique environment description (threats and defenders). By comparing these criteria, the process helps to determine a set of appropriate scenarios that will support the desired analyses.

Two ongoing analysis efforts at APL—sponsored separately by the Office of Naval Research and the Navy Theater Wide (NTW) program—have been testing different TBMD EC concepts through modeling and simulation. These two efforts have coalesced the specific characteristics and methodology for scenario selection into the process discussed in this article.

BACKGROUND

The challenge for the defending force is to use all available defensive systems in a combined arms approach and to select appropriate intercept opportunities with the available resources. Through EC, a preferred shooter is selected to engage each threat so that a raid—one that would overwhelm any individual unit—can be handled by the coordinated force. The performance of EC is measured primarily by

- *Leakers*: number of threats that reach their targets
- *Free riders*: number of threats that reach their targets without being engaged
- *Unintentional overengagements*: number of interceptors the force launches per threat in excess of the firing doctrine

The choice of preferred shooter, along with weapon choice and intercept time (which together constitute a "preferred shot"), can be made using one of several methods,[4] distinguished by four main characteristics.

1. *When the decision is made*. Decisions can either be static (predetermined and fixed during the planning phase; based on rules that are not sensitive to temporal situational changes) or dynamic (based on the reactions and capabilities of other units as the raid unfolds). Static concepts do well at minimizing unintentional overengagements; however, if a single unit becomes saturated, no mechanism is available for transferring engagement responsibility to another unit.
2. *Basis for the decision*. Decisions can either be unbidded (no external data on other units' capabilities and intentions are used to make decisions) or bidded (data may be obtained on other units' intentions and capabilities prior to making a decision). By employing universal measures of performance, bidding allows units to decide on the preferred shooter without detailed knowledge of the capabilities of the other units' weapons, but comes at the expense of increased data exchange requirements and increased time to make the decision.
3. *Where the decision is made*. Decisions can either be decentralized (decisions are made locally by the TBMD unit on whether to engage) or centralized (decisions are made in one location by a "master unit," and orders are sent out to all TBMD units). Loss or disruption of communications to individual units employing decentralized concepts is less likely to perturb coordination among all other units. This helps to avoid the vulnerability of centralized methods to single-point failure at the risk of potential inconsistencies in the decisions made.
4. *Decision-making frequency*. This relates to the periodic threat reassessment and recalculation of engageability and schedules to respond to new or updated tracks. Iterative decisions are capable of responding to changing/developing situations that even dynamic, noniterative concepts may not be able to do.

Taken in their simplest form, raids present three different situations for preferred shooter solutions: (1) mutually exclusive, (2) multiple choice, or (3) single optimal solution. Mutually exclusive situations (Fig. 1a) involve threats that have only one possible threat–weapon pairing solution; no EC is required. Multiple choice (Fig. 1b) involves threats that can be engaged by more than one unit and results in multiple solutions with only marginal differences in performance. A single optimal solution (Fig. 1c) involves a combination of shared and unique engagements, so that the choice of preferred shooter will result in different levels of performance for different EC concepts, depending on threat timing and the relative geometries of the engagements. Situations like those shown in Fig. 1c demonstrate solutions that are nontrivial and represent challenging or stressing conditions for a battle force. ("Challenging" or "stressing" refers to situations in which resultant performance levels are near or outside the acceptable margins called for in system specifications.)

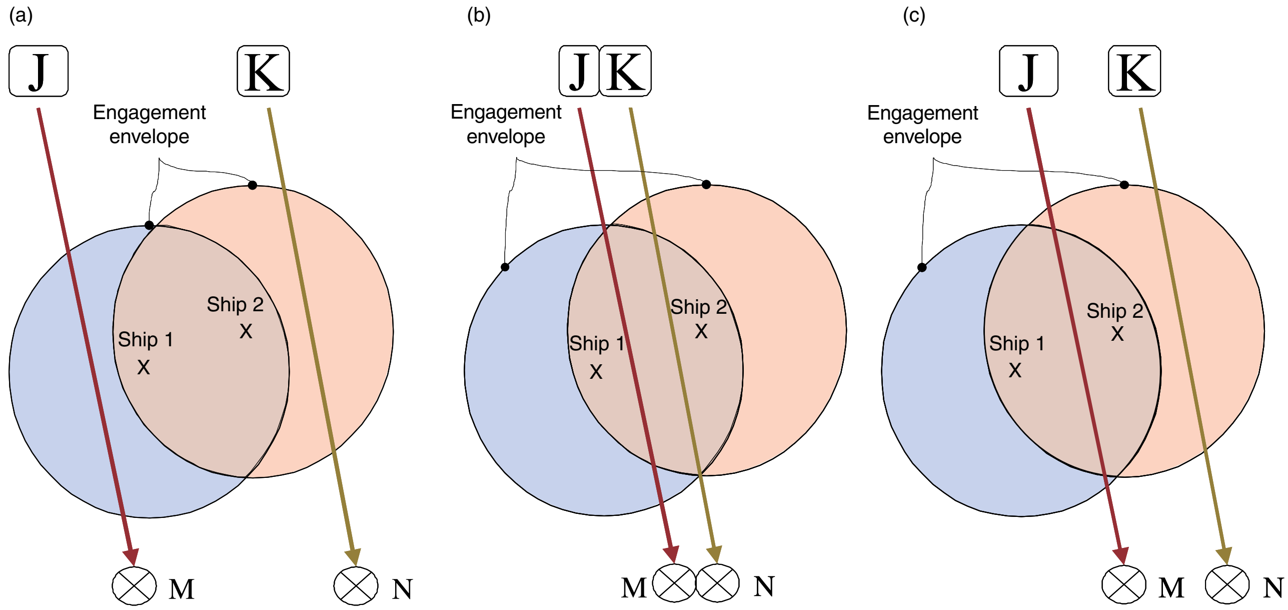


Figure 1. Ground-truth views of threats and engagement envelopes show three possible situations for resolution of threat–weapon pairings: (a) mutually exclusive, (b) multiple choice, and (c) single optimal solution.

For example, in the case of Fig. 1c, the EC concept of "shoot-and-shout" might lead to less-than-optimum results. Assume that ships 1 and 2 have identical resource capabilities in sensors, weapons, and communications. Ship 1 is in a position (as defined by the engagement envelope shown) to engage threats headed toward impact at defended asset M on a trajectory from launch point J (hereafter called "threat J"), while ship 2 is in a position to engage threat J or K. Assume for simplicity that each ship can only engage one threat at a time. In that case, ship 2 will launch first against threat J because it has an earlier intercept time, and then will inform ship 1 that it has done so. If threat K were launched a bit later than threat J, ship 2 would have a later launch time against threat K compared to J. Because ship 1 cannot engage threat K and ship 2 is busy with threat J, threat K becomes a free rider. The same situation can occur for other reasons, such as when dissimilar platform capabilities are employed.

However, consider an iterative distributed engagement decision-making EC concept in which each unit informs the others of its engageability against each threat and locally arrives at the same conclusions as to which unit should shoot. In this concept, the initial assignment could be the same as in shoot-and-shout. As long as threat K is detected before launch against threat J by ship 2, distributed engagement decision making would still be able to make the reassignment decision. Thus, there would be no free rider.

Compensating for performance shortfalls resulting from the use of a particular EC concept will have a potential impact on other system areas. For the previous example of shoot-and-shout, success against a raid would require changes in system requirements and design, such as discrimination of one of these threats by the nonlaunching ship or forward pass of the in-flight interceptor missile's engagement to the other ship, among other options. Through the use of scenarios, the analyst can help identify the extent of the shortfalls of proposed EC concepts and their impact on overall system performance; thus, a critical need exists for the development of appropriate scenarios.

SCENARIO DESIGN SPACE

Scenarios are constructed to reflect the primary elements or driving factors that affect performance in the analysis problem space, as shown in Fig. 2. "Environment" comprises the set of physical situations in which the threats and defending forces must operate. This is not just a matter of geography, but can include aspects of weather, time of day, and general atmospheric conditions. "Threat capabilities" contain all possible tactics and weapons either currently in use, expected to be used in the timeframe of the then-fielded systems, or theoretically possible. Traditionally, the most influential driver has been "defender capabilities" or engineering design requirements. (These can include the minimum set of capabilities the user will accept, referred to as "threshold requirements," and the set that the end-user would prefer, referred to as "objective requirements.")

While typically scenarios have been devised on a single-platform basis, more recently[5] emphasis has been added on force-level support capabilities that allow available assets to operate together as a "family of systems." This functionality beyond the unit level includes such

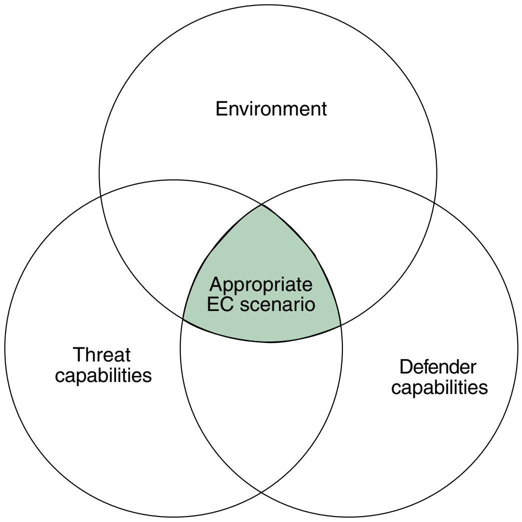


Figure 2. Scenario design space.

abilities as battle force interoperability (standard representation and understanding of messages), common air picture, and EC, but raises issues concerning the impact of timing, latency, and connectivity on force-wide performance.

An appropriate EC scenario is the intersection of the three drivers in Fig. 2, which should be viewed as an instance of a single scenario. Scenarios selected should have enough elements of the three drivers to provide a more complex problem space and multiple solutions, some better than others, to allow performance sensitivity analyses. Different scenarios would have different-sized intersections, indicating some that may be more appropriate than others.

SCENARIO CHARACTERISTICS

As discussed previously in relation to the situations in Fig. 1, the most appropriate type of scenario occurs when at least one optimal solution set (i.e., one that minimizes leakers, free riders, and unintentional overengagements) of unique weapon/unit/threat assignments exists with numerous possible suboptimal solution sets. Incomplete coverage overlap (i.e., all targets are not engageable by every unit) and oversaturation of at least one unit (i.e., higher localized raid density than the unit can handle) are examples of conditions that should highlight the differences among various approaches to EC. However, threat capabilities, raid geometry and timing, defended asset characteristics, defending force composition, and defending unit capabilities all impact engagement decisions. Thus, a combination of factors and criteria characterize challenging scenarios for battle force EC concepts.

The criteria that were considered in the selection of scenarios for initial EC analyses fall into the three categories presented in Fig. 2 and are discussed below.

Environment

A complete scenario will involve a representative environment. Elements of the environment are the terrain (including defended assets), weather, atmospheric conditions, and time of day and year. It may also include all air traffic (friendly, neutral, and hostile), communications traffic, and command structures. For the purposes of EC scenario selection, environmental elements that should be considered are described next.

Geography (Theater Location)

Where possible, one must use the theaters identified in existing scenario documentation relevant to the TBMD program(s) involved. Locating stressing operational situations in multiple theaters provides a greater variety of geometry in which to compare EC alternatives. Unlikely theaters (e.g., Chile attacking Antarctica) or fictitious theaters (Persian Gulf attached to Yellow Sea) should be avoided.

Defended Assets (Threat Impact Points)

Multiple defended assets can complicate coordination because it is more likely that different units will have different capabilities and responsibilities versus the threats headed to these impact points. These assets should be in valid locations (in theater and in friendly occupied land and sea areas). The number, size, and dispersion of areas that an enemy might threaten present challenges in planning a blue force laydown, including the assignment of and interactions with one or more blue force units in the defense of these assets.

Threat Capabilities

The threat capabilities in EC scenarios consist of the threat platforms used—whether current or expected near-term weapons systems or systems that are technically feasible—the tactics used in their deployment, and aspects of the defender's reactions to the threats. The overall order of battle, with emphasis on the TBM order of battle, is also part of this consideration. Large raids, having several different assets targeted over the entire range of the theater, are a probable approach and may be more credible.

Striking multiple targets would be a tactic used to overcome defense capabilities and permit at least one site to be destroyed (this assumes multiple objectives for an enemy); other tactics might target more than one asset in the expectation of overcoming multiple sites. However, different tactics should also be considered, such as attacking a single defended asset with a large raid, while basing the placement of defending units on covering the entire theater's defended asset list. As with the environment, there is a subset of threat criteria that helps focus selection of an appropriate EC scenario.

Types of Threats

Different defender units may be designed to engage dissimilar sets of threats (i.e., different separating and/or nonseparating threats with different ranges). The inclusion of mixed threat types can make the situation more realistic and potentially more challenging. This is especially true for separating threats and those with weapons of mass destruction. However, it is not realistic to include all required/known threats for the world's order of battle within a single country's inventory.

A raid of a mixture of threat types provides a suitable representation of all the threats that a force can be expected to encounter at a given point in time. A battle force will contain different unit types developed to defend against specified threat sets, which will differ, even among units whose missions may be similar. Two examples are Theater High-Altitude Area Defense (THAAD) and NTW. THAAD is a ground-based BMD platform countering the terminal phase of ballistic missiles in the exo- and high endo-atmospheric regions; NTW counters the exo-atmospheric midcourse phase of ballistic missiles and recently was renamed Sea-Based Midcourse Defense.

In the formulation of a raid scenario, allocation of some number of each threat type should be considered, either equally distributed among types or as a proportional weighting of one type over another. At the same time, consideration must be given to reality—that the mixture is representative of what a particular enemy has or can be projected to have in the quantities to be represented in the scenario (if not, the credibility of the scenario might be suspect).

Position

This aspect consists of valid locations for threats in the engagement, in particular valid locations for launch sites (generally enemy-occupied land areas, although sea-based positions may be posited). Multiple launch areas are likely. While a particular type of threat might be restricted to a single launch site (because of fixed launch facilities), many will be mobile. A balance must be struck here. Although each threat might be launched from a different site, it is also true that, depending on the size of the launch area, multiple launches may occur there. The possibility of launches outside these most likely areas should not be completely excluded from consideration because intelligence updates may ultimately expand the definition of probable launch sites.

Number of Threats

The preferred minimum value for raid size is the threshold raid size of the program(s) of interest if one of the goals is to test requirements. If a goal is to test against the projected capabilities of an adversary and if this is the initial raid of a conflict, then the adversary's maximum capability should be used. If this is not an initial raid, the adversary's capability will likely not be maximized because of attrition or lack of setup time.

Additionally, there may be requirement inconsistencies across documents and platforms. Required raid size is usually well defined. For example, required raid sizes have been called out in the NTW System Requirements Document and Navy TBMD Operational Requirements Document (ORD), but the Capstone Requirements Document for TBMD has its own values; other programs' raid sizes may also differ.

Raid density is not as straightforward, however. Required unit raid densities have been called out in the NTW System Requirements Document and Navy TBMD ORD but may differ from an overall required force raid density and may also differ by platform. For a single force raid density value to apply to a scenario with dissimilar systems, the minimum values of force raid density (derived from the applicable documents of the participating systems) must be used; this situation may result in some units not meeting a minimum unit raid density requirement, but should be considered.

Raid timing should also be taken into account. Threats launched with a distribution over seconds will affect TBMD performance differently from threats with a distribution over minutes.

Threat Engageablity

Threat engageability is more an analysis criterion than any of the others discussed so far and deals with whether all threats are potentially engageable. To be engageable, the threat must come into range of a defending unit's weapon system. This does not make any assumptions on whether a unit should engage, only on whether a unit is capable of engaging a particular threat. It also does not mean that all threats will actually be engaged, only that the possibility to engage exists.

All threats included in a scenario should be engageable by some portion of the defending force. If at least one threat is not engageable, then the scenario represents an imperfect force laydown, a lack of sufficient forces to accomplish the objectives, or insufficient unit capabilities.

Defender Capabilities

The focus for EC scenarios is on the TBMD units and their capabilities, taken separately and as a force. Elements in this domain include the order of battle of defender forces, the threshold and objective requirements levied on individual systems platforms and on the battle force, the laydown of all the forces, and the capabilities the force has to support fighting. As with the other drivers for EC scenarios, APL has identified a subset of criteria, described next, that supports the selection process.

Firing Units

Force composition in the timeframe analyzed should be considered in developing more realistic scenarios. For EC analyses, there must be at least a minimum number of units to perform coordination. Force-wide, this minimum is at least two TBMD units, with three preferred. The values should be higher if coordination among the same type of units is also to be considered (e.g., two from program X and two from program Y, when programs might envision coordinating with like units before coordinating with unlike units). While two units provide coordination, decisions are limited to the selection of one or the other unit (or none); additional units provide more than one alternative to a main firing unit and increase the number of potential solutions for the entire raid.

The number and types of TBMD units included in the scenario will also affect the outcome of EC. Analyses focused on the program-specific level are straightforward because they involve only one type of TBMD unit. However, a mission-area analysis will involve platforms developed under more than one program. For TBMD, this is complicated by the fact that some units have different roles in a layered defense. They can be midcourse or terminal. Also, in a multimission situation, particularly the case for Navy vessels, there will be units with more than one mission operating simultaneously, competing for system resources.

A further consideration is whether the EC concept will make decisions that take into account all mission areas (e.g., Theater Air and Missile Defense [TAMD], composed of related missions such as TBMD, Anti-Air Warfare [AAW], and Overland Cruise Missile Defense [OCMD]) or will make decisions for each warfare area separately and independently of other mission areas and/or services.

Position

This aspect consists of valid locations for defending units based on terrain and bathymetric data (friendly land sites for ground-based units and sea-based areas for sea-based units in deep enough water to support the ships and far enough off shore from enemy positions to be defended by friendly forces). Also, TBMD units need to be positioned where they can defend all their assigned assets against all of the assigned (suspected) threat launch areas. Many existing scenarios place units where they cannot go (e.g., ships in shallow water) or cannot execute their assigned mission.

Depth of Fire

A good defense-in-depth design will place firing units to maximize force-wide reengagement opportunities, as well as to provide redundant coverage for the higher-priority assets. The coverage and depth-of-fire assessment is usually based on an analysis of the engageability or probability of kill and time of flight of weapons against given threats. However, there are not always enough units in the theater to provide robust defense in depth, and a good blue force laydown is not always a goal of the scenario. Thus, to make challenging and realistic scenarios, instances of unique firing units (i.e., no other unit has opportunities against a given threat) often should be included.

Mission Representation

While the focus of this article is on the development of scenarios to support TBMD EC analyses, Navy platforms tend to be multimission in nature. As such, resource availability for those specific units may be further limited. Thus, depending on the analysis involved, more than one mission (i.e., AAW and TBMD) may be considered.

If more than one mission is to be represented, the question of whether the scenario supports all the required missions would also need to be considered. Nearly simultaneous threats in multiple TAMD mission areas (e.g., AAW and TBMD) represent a massed raid in which an enemy coordinates weapons from a spectrum of approaches (e.g., TBM, overland cruise missiles, and air breathers) to overcome the abilities of defenders. At the program and mission area levels, this has not been considered an issue because these were generally single-mission oriented; however, the TAMD Capstone Requirements Document and the Navy TBMD ORD contain key performance parameters for interoperability, and the basis of the interoperability parameters is compliance with a set of interoperability exchange requirements. The scenarios will need to support these requirements. So although mission representation is not the subject of this article, it is listed for the sake of completeness.

METHODOLOGY

APL analysis efforts have led to the developed a scenario assessment process (Fig. 3) consisting of identification, evaluation, and selection. "Identify candidate sources" is the process of finding potential sources of existing scenarios relevant to the analysis; this may include missions of interest, force laydowns, or details on a theater of interest (terrain, air and surface traffic, and weather). "Assess candidates" is the process of determining values for a set of metrics for each candidate scenario. APL found that a combination of visual inspection of the numbers of different objects (launch and impact points, threat types, and defending units) and a tool that can generate launch and intercept windows (e.g., EADSIM, the Extended Air Defense Simulation) provides a reasonable method for performing the needed calculations. "Select scenarios" provides a small subset of candidates for use in the analysis. If no suitable candidates are found after going through this

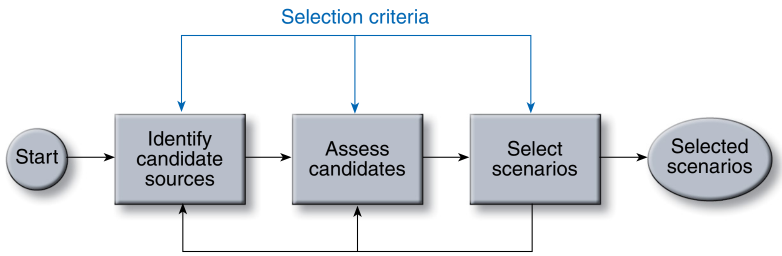


Figure 3. Methodology process.

process, variants on the candidates should be tried; if that fails, new scenarios should be developed. In either case, this same process should be applied.

Many scenarios may be considered as candidates, but some may be more appropriate than others. To determine which would work best, benchmark criteria values need to be established against which scenarios can be compared. Benchmark criteria should be traceable to existing plans, documentation, intelligence, and operator experience. In some situations, none of the scenarios selected as candidates may meet the minimum conditions of these other criteria. In those cases, the criteria should be relaxed, either by loosening the strictures of a given criterion or ignoring certain criteria.

Another consideration is the development of composite stressing scenarios. Because candidate scenarios are derived from different programs, composite scenarios (as in multimission ship operations or Joint TBMD analyses) are possible. In these composites, appropriate elements from different sources fill in the full picture of the theater (weather, all forces, terrain, and activity) to support simultaneous multiprogram, multiservice, multimission operations.

An example of elements that may be included in a composite scenario is given in Fig. 4. Activity time periods for events related to multiple missions (TBMD, OCMD, and AAW) are indicated along with threats for different programs (endo- and exo-atmospheric TBMs) and a background (level of communications traffic, air traffic, weather, and terrain).

At the core of the process is a checklist that gives the analyst a method for determining the appropriateness of a given scenario. Not all the items on the list have to be satisfied. However, if a particular item is not involved then the analyst should understand why the scenario is still valid.

At times during "what if" analysis, values will be used that are larger or smaller than the documented requirements values. For example, if a scenario results in too many leakers, then one may want to examine with lesser values whether the increased numbers of leakers is linear or has some knee in its curve. Also, one or two targets may, at times, be unengageable. This knowledge could be useful when evaluating scenario variants such as the impact on the EC concept when a shooter or a command and control node is destroyed.

The selection of scenarios can be considered a two-step process involving the checklist in Table 1. In the first pass, the analyst evaluates a candidate scenario based on the minimum that it must do. This means that the scenario, as presented, meets a minimum set of acceptable criteria; as soon as a scenario does not meet one criterion, it is not a candidate for the second pass. In the second pass, the analyst evaluates each surviving scenario and assigns quantitative values using visual inspection and simulation tools. These scenarios can then be compared to determine their relative worth.

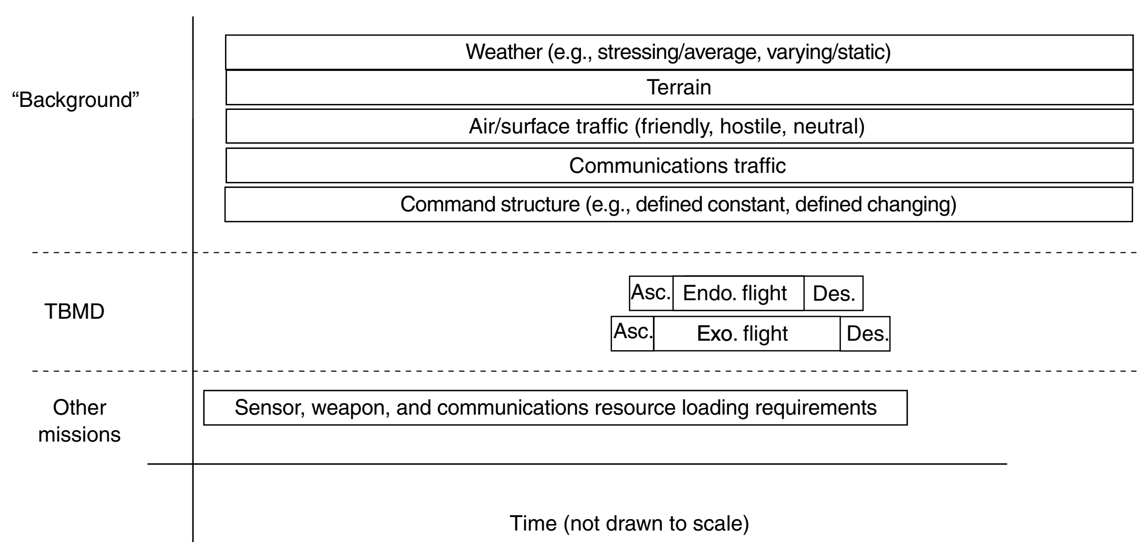


Figure 4. Example of a composite scenario.

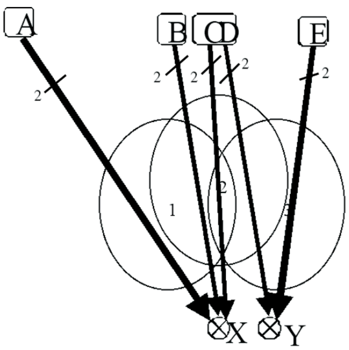
Table 1. Two-pass methodology checklists in terms of scenario characteristics.

Charact-eristic	Checklist: Pass 1	Checklist: Pass 2
Theater location	Use of TBMs possible/likely	
Positions	Blue Navy forces not too close to the adversary's shore-based defenses	
	Water not too shallow (no ships on the beach)	
	Blue land units placed within the blue sector (unless it is an aircraft or special operations forces)	
	Red forces in appropriate locations for the aggressor (no land launch points in the middle of the blue sector)	
Threat impact points	Multiple defended assets	Raid density in terms of threats for each defended asset (as demonstrated in a histogram binned by threats per defended asset, labled "Pass 2 DA Raid Density" in Figs. 5 and 6)
Types of threats	A mixture of types, with preference to having at least one of each threat type represented	How well the threat types are represented
		Multiple threat types present simultaneously, which can be determined by comparing a chart of intercept and launch windows for each unit against each threat (to be found in Figs. 5 and 6) with their associate threat types
Numbers of threats	Contain the appropriate ORD/system requirements document specifications (threshold for minimum value and objective for maximum value); flexibility desirable	
	Force raid size commensurate with the number of units involved (i.e., the product of number of units and required unit raid density; e.g., if the required unit raid size were 2 threats per unit and there were 4 units, then a force raid size of 8 would be minimally acceptable, even if the required force raid size were 6 threats or 12 threats)	
	All units have at least a minimum required raid size density at the unit level, as demonstrated in a table of ships and associated count of threats per ship to be found in Figs. 5 and 6	One or more units with a maximum required unit raid density
	Units have at least the minimum required raid timing relative to requirements	Raid timing permits multiple threats to be in engagement evelopes simultaneously
Engage-ability	All threats (that a platform is designed to engage) are engageable at some point in their flight paths as demonstrated in a table of threats and associated count of ships per threat, labeled "Pass 1 Engage-ability Test" in Figs. 5 and 6	Number of threats that have only one potential defender that can engage. This is demonstrated in a histogram of the number of threat instances binned by the number of ships that can engage a threat, labeled "Pass 2 Engageability Test" in Figs. 5 and 6
Firing units	Multiple shooters—program-specific (e.g., Navy Area and NTW)	Mission-specific (e.g., TBMD) with multiple platform types
		Multiple shooters—multimission with multiplatforms
Depth of fire		Unit and force depth of fire for each threat (as demonstrated by a table representing intercept opportunities for each unit against each threat and for the force as a whole against each threat, labeled "Pass 2 Depth of Fire Test" in Figs. 5 and 6). To calculate unit/force depth of fire, assume a probability of kill of zero and perfect kill assessment; calculation results in, at most, how many times the platform and force can take a shot
Mission representation	How many warfare areas are supported by the scenario, and are they the correct warfare areas for the analysis?	Nearly simultaneous threats in multiple TAMD warfare areas

EXAMPLE APPLICATIONS OF THE METHODOLOGY

The methodology can be illustrated with a pair of scenarios to be reviewed as potential candidates. Because of issues with classification, the examples described here are generic and hypothetical but still serve to illustrate the methodology. Figures 5 and 6 contain elements used to evaluate the relative merits of the two scenarios (for brevity, a subset of the features described in this article is presented). The upper left portions of Figs. 5 and 6 show a graphic of the force laydown and scripted threat trajectories and can be used to calculate the pass 1 tables. The intercept and launch window charts in the center of Figs. 5 and 6 identify the intervals of time in which each ship unit can launch against each threat with at least a minimum acceptable probability of kill and in which each launched missile can be expected to intercept the threat. (The pairs of threats with the same launch and impact points are illustrated here by only one of the pair for simplicity.) This chart serves as a basis for calculating the values in the pass 2 tables on the right of Figs. 5 and 6.

Figure 5 shows a representation of a raid of 10 threats, launched in pairs (labeled in the intercept and launch window chart and in the figure's tables as A1, A2, B1,

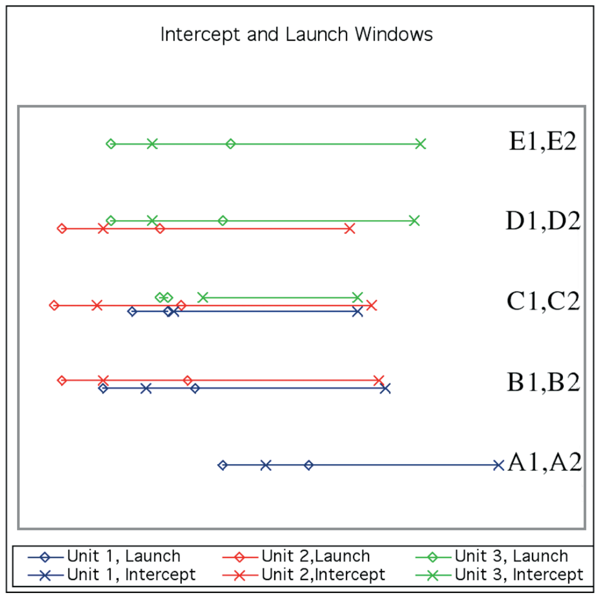


PASS 1 SHIP RAID DENSITY

Ship	Threats per Ship
1	6
2	6
3	6

PASS 1 ENGAGEABILITY TEST

Threat	Ships per Threat
A1,A2	1
B1,B2	2
C1,C2	3
D1,D2	2
E1,E2	1



PASS 2 DA RAID DENSITY

Defended Asset (DA)	Threats per DA
X	6
Y	4

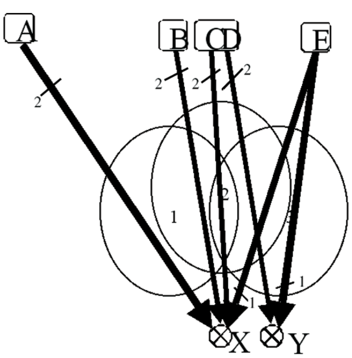
PASS 2 ENGAGEABILITY TEST

Number of Ships that Can Engage a Threat	Number of Instances
1	4
2	4
3	2

PASS 2 DEPTH OF FIRE TEST: INTERCEPT OPPORTUNITIES

	UNIT			MAX. TOTALS	
THREAT	1	2	3	UNIT	FORCE
A1,A2	4			4	4
B1,B2	4	4		8	6
C1,C2	2	4	2	8	6
D1,D2		4	4	8	6
E1,E2			4	4	4
	TOTAL			32	26

Figure 5. Feature summaries, first candidate scenario.

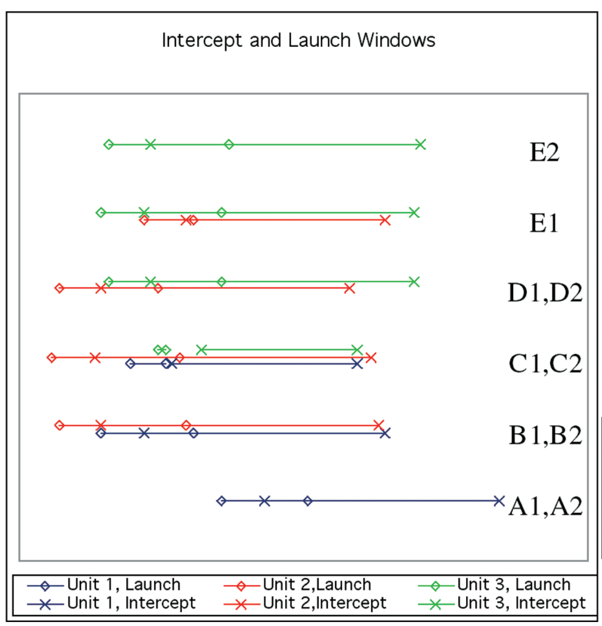


PASS 1 SHIP RAID DENSITY

Ship	Threats per Ship
1	6
2	7
3	6

PASS 1 ENGAGEABILITY TEST

Threat	Ships per Threat
A1,A2	1
B1,B2	2
C1,C2	3
D1,D2	2
E1	2
E2	1



PASS 2 DA RAID DENSITY

Defended Asset (DA)	Threats per DA
X	7
Y	3

PASS 2 ENGAGEABILITY TEST

Number of Ships that Can Engage a Threat	Number of Instances
1	3
2	5
3	2

PASS 2 DEPTH OF FIRE TEST: INTERCEPT OPPORTUNITIES

	UNIT			MAX. TOTALS	
THREAT	1	2	3	UNIT	FORCE
A1,A2	4			4	4
B1,B2	4	4		8	6
C1,C2	2	4	2	8	6
D1,D2		4	4	8	6
E1 (to X)		2	2	4	3
E2 (to Y)			2	2	2
	TOTAL			34	27

Figure 6. Feature summaries, second candidate scenario.

B2, etc.) from 5 launch sites (A, B, C, D, and E) toward 2 impact points (X and Y). Three units of the same type (e.g., upper-tier ship-based) are defending with similar engagement volumes through which these threats pass. Different threat types originate from each of the launch areas.

Assume for this generic case that the defending system is required to have capability against 5 threat types (a threshold raid size of 10 with an objective of 20) and threshold unit raid densities of 2 threats per ship with an objective of 4. Figure 6 shows a second scenario, similar to the first, having the same number of launch points, impact points, and defending units. However, one launch complex, labeled E, launches one TBM at asset X and its second TBM at Y, while A, B, C, and D target their pairs at only one of the two impact points.

In pass 1 of the methodology, both scenarios can be identified as candidates. The relevant criteria values can be determined from the scenario laydown and column of tables on the left of Figs. 5 and 6. Unit raid sizes are identical and are within the range of force raid size as defined in the checklist. All units meet and, in this case, exceed the objective values of the number of engagements they can support. The same units exist in both scenarios. In fact, for every item in the first pass, these two scenarios are almost equal candidates, with the slight differences visible in pass 1 tables of Figs. 5 and 6.

It is in the second pass that the differences between the two scenarios appear more pronounced. Because of the shift of one TBM aimpoint, one of the three firing units has engagement opportunities against one additional threat than it did before without detriment to the number of threats that the other two could engage. In most cases, the launch and intercept windows overlap; if the firing policy is assumed to be a single salvo with a shoot-look-shoot capability, most of the firing units can launch a second interceptor missile before the launch window closes (in some cases, a third shot might be possible). However, there are instances where a unit may only launch once. The result of these differences is a slightly greater depth of fire and more engagement opportunities in Fig. 6, at the expense of slightly fewer threats having only one ship that can engage them. This implies that Fig. 5, because there are more instances of single-solution threat–weapon pairings, may be more likely to present different performances between different EC concepts.

Both of these examples are well qualified for use in analysis activities. However, if one were to prioritize them for evaluation, Fig. 5 would be the first choice.

CONCLUSIONS

The basic methodology described herein was applied in the selection of an existing scenario for ongoing NTW EC analyses. Often there will be a clear indication, even after the first pass, that one scenario makes a better candidate than another. However, in cases where scenarios are very similar, this methodology helps to identify which conditions are more likely to yield cases that demonstrate differences in EC concept performance.

The purpose of the methodology is to identify that intersection of threat, platform, and environment that will be applied to all EC concepts. This is only the first step in the analysis effort; the actual application of the scenarios to the different EC concepts and a comparison of their resulting performance are separate tasks. Such comparisons may lead to the identification of conceptual shortfalls that should be taken into account during the actual system design phase.

The methodology indicates a number of different directions in which further research could be performed. Three such avenues are discussed in the following paragraphs.

The first area is the extension of this methodology to support the automated generation of new scenarios. Quantification of the checklist would support this process by providing a figure of merit for comparing separate scenario instances in terms of relative fitness, which is similar to a strategy identified for scenario management.[6] For instance, a figure of merit for the composition of a scenario raid (the number of threats of each threat type in the raid) could be based on how equally the threat types are represented, or as a weighting of one type over another. One could posit a tool that could investigate which mixture would provide the best challenge to a given force or which mixture of defending assets would be most successful against a given threat mixture.

A second area for further research is the generation and evaluation of scenarios using a Monte Carlo approach. Here, the TBM order of battle would be fixed and allocated to specific launch areas. Mobile launchers would randomly wander from their bases and randomly target a perceived defended asset area (to fulfill a raid quota or as weighted by asset priority). The TBM impact points would differ from the intended asset location (potentially resulting in missing the targeted defended areas, which could lead to the decision not to engage the threat by the TBMD platforms). In addition, their flight paths and orientations would differ from specified nominal values. TBMD units would be assigned operating areas but would assume random positions within those areas for each experimental run. This approach would constrain threat capabilities while tailoring tactical flexibility to present varying realizations of what might occur.

The focus of this article has been on the selection of scenarios for one mission area only, but, as noted, other missions are also part of the equation. Navy surface combatants are typically multimission in nature, and a coordinated enemy attack involving a variety of simultaneous air and missile weapons may severely tax force resources.

Figure 7 depicts this extension of the composite scenario shown earlier in the article. The extension of this methodology to multimission operations is a logical, albeit challenging, next step. The methodology attempts to quantify situations, but to date has not directly addressed the issue of multimissions. The relative importance of one mission area over another is subjective in nature, so quantifying relative importance and obtaining community concurrence in the weighting of these different missions will be contentious. However, this is an area in which further investigation is warranted because these mission areas are very different, yet have overlapping resource requirements (use of sensors, launchers and permitted simultaneous engagements).

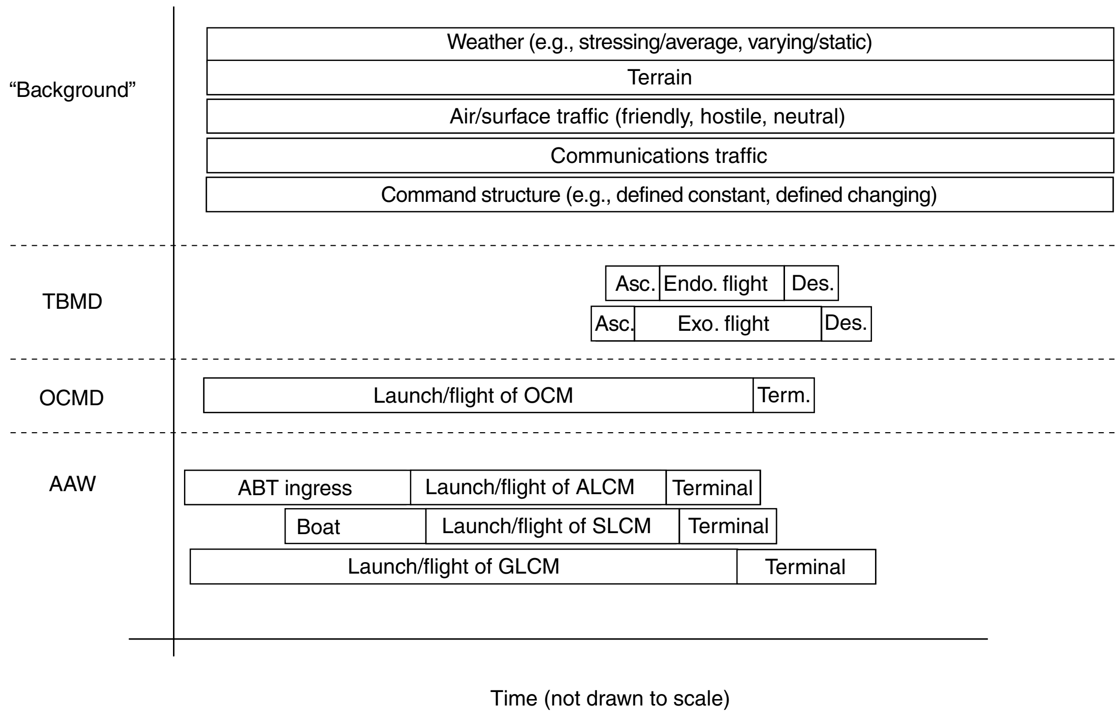


Figure 7. Example of composite, multimission scenario (ALCM, GLCM, and SLCM are, respectively, air-, ground-, and ship-launched cruise missiles).

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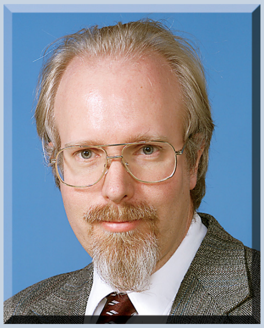

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