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Preparing Today for the Mines of Tomorrow

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PREPARING TODAY FOR THE MINES OF TOMORROW

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To the inquiry, "What simple initial threat do I need to blockade a port with mines?," various responses present themselves. *Simple initial threat* is basically the probability that the first vessel to attempt transiting the minefield will become a casualty, so that it no longer can perform its mission. The *simple initial threat* might be very low because the enemy is not very determined to overcome the minefield; it might be very high because the enemy is very determined to do so. An enemy with a strong mine countermeasure presence or one willing to accept a high degree of risk simply might channelize through the minefield and accept whatever attrition occurs, making *simple initial threat* a useless measure of effectiveness (MOE) for blockading. The question asked above seeks to determine what conditions determine the *simple initial threat* from mines that would be needed to accomplish designated objectives, or whether another MOE would be more suitable for the purpose.

Historically, maritime mine warfare has been called on to achieve various effects to support naval strategies.[1] Land mines have provided a means to achieve some similar objectives; while there are certainly variations between maritime and land mines, the core principles are remarkably similar. The methodology for determining how many maritime mines are required to achieve a desired effect has never been evaluated fully, because of the complexity of the subject—including important factors

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rooted in human psychology. MOEs currently in use are informative but do not answer the question of the level of risk that mines need to create to achieve a particular goal, such as closing a port. This article adapts methodologies developed for land mines/obstacles to maritime mining, owing to their inherent similarity; aligns MOEs to operational objectives; explores developmental mining concepts; and presents new MOEs for maritime mines.

Maritime mines generally will not win a war by themselves; however, they have the potential to change the outcome of a war by complementing other platforms and weapon systems. Incorporating mines to complement submarine, surface, air, land, and special forces can increase force effectiveness exponentially. In that regard, commanders should understand clearly how maritime mining effects can be used to increase the capability of the fleet and to dictate operational maneuvers and efficiency of movement. History has demonstrated that mines are a strategic weapon that can inflict physical and psychological damage that impacts the military, economic, and political wellness of an enemy sufficiently to change the course of a war.

Physical damage, such as the sinking of a ship or damaging of it to the point where it aborts its mission, is often the grading scale associated with the MOE of a minefield. However, other grading scales do not depend on physical damage. If the intent is to create a barrier and the declared minefield affects enemy movement, the field has merit. The mine is not the primary weapon; it is a subset of the primary weapon—the minefield itself. History provides examples of minefields being very successful despite augmentation by decoy mines, or even being made up entirely of decoy mines, or simply being declared fields without any weapons in them at all. The last case, especially, shows us that a minefield's greatest threat is not to enemy shipping but to the enemy psyche. Greer and Bartholomew point out that "the real effect of a minefield derives from a subtler influence—an exaggerated fear."[2] However, a "brittle" minefield can be pierced easily by countermeasures and then might collapse, negating the intended effect. It is important that the enemy experience a robust minefield capability that is replicable if we are to capitalize on that exaggerated fear—a fear that may be strong enough to allow a minefield without mines to be durable over time. This article starts from the original question, reviews the concepts currently in doctrine, and offers ideas on how to extend beyond them.

A BRIEF HISTORY

The lessons the Russians learned during the 1904–1905 Russo-Japanese War about the impact of both defensive and offensive mining were not lost on the participants in the two world wars.[3] Russian mines were more effective against

Japanese battleships than the Russian fleet was. However, as noted, the fear of a minefield can have effects beyond the sinking of ships.

During the First World War, Germany, Austria-Hungary, Italy, France, and Great Britain lost 240 submarines, with mines or mine-nets causing sixty-eight of those losses. Germany lost thirty-eight U-boats to these causes, with the Dover Barrage (a minefield aimed at denying German submarines access to the English Channel) claiming sixteen of them in the last year of the war. While the loss of sixteen submarines is significant, the real power was in the strategic value: the barrage forced the U-boats to take a much longer route to begin their operations, which had critical effects on the submarine population and the boats' time in an operating area. While the Germans focused on the tactical aspects of mine warfare, sinking more than one million tons of Allied merchant shipping, the Allies understood the strategic value of mine warfare.[4] At Gallipoli the Allied powers, despite having a clear advantage in overall military capability, learned how devastating a minefield supported by gunfire can be. The combined threat caused the Allies to pause when they should have pressed forward, and this inaction by Allied commanders caused their mission to fail.[5]

Mines also played a major role in the Second World War, for both Allied and Axis powers, with mines used to achieve strategic effects.[6] For example, while some criticize the Northern Mine Barrage (defensive minefields designed to restrict German access to the Atlantic Ocean) for a lack of kills (although some kills may have gone unnoticed and uncredited), the mine barrage is what caused *Bismarck* to be detected, which eventually led to its sinking in May 1941.[7] In the Pacific, mining in Palau trapped thirty-two Japanese ships in port, providing a target-rich environment; Allied aircraft sank twenty-three ships and damaged the remainder with bombs and torpedoes in March 1944. Mining also contributed to the sinking of ships by forcing vessels away from mined coastlines, which allowed radar to direct aircraft for attacks in the open ocean. The Japanese navy responded to maritime mining by abandoning anchorages at Palau, Penang, and Kavieng in the western Pacific area. Ground forces also benefited from naval mining because disruptions in supply caused problems for the Japanese army in China, Burma, Siam, Malaya, and Indochina.[8]

Contrary to popular belief, both world wars brought the fight to the shores of the United States, and maritime mines played a huge role in submarine shore defense, which kept supply ports open and ensured that major military and industrial complexes remained operational in support of the war effort. The National Park Service notes that in the defense of San Francisco Bay, "[i]f the big guns failed to stop an enemy vessel far offshore, the next line of defense was three minefields."[9] Later, in Vietnam, the mining of Haiphong Harbor in 1972 did what bombers alone had seemed unable to do: impose coercive diplomacy. Maritime mines closed the port, which forced supply lines to go overland, making the bombing campaign incredibly effective against trucks and trains. Because of the lack of supply routes, the North Vietnamese offense stalled; in fact, the North Vietnamese were unable to initiate any major offensive campaigns. This effect is credited widely to the maritime mines that prevented the resupply of their forces. Thus, maritime mines were the major factor in bringing North Vietnam to the negotiating table and in the release of American prisoners of war. One has to wonder what the outcome of the war would have been had suggestions from Admiral Thomas H. Moorer, USN (Chairman of the Joint Chiefs of Staff), for the mining of major ports not been ignored earlier in the war.[10]

As referred to above, the value of a mine often is in its second-order effects. Mines have limited U-boats' time on station, facilitated the sinking of enemy ships by aircraft, caused ports to be abandoned, made land campaigns difficult by choking replenishment, and kept harbors safe, and have been the weapon of choice for coercive diplomacy. A minefield is completely capable of achieving its objective through the attrition of enemy vessels that transit the minefield, or through fear of the minefield, which may cause enemy forces to avoid potential losses, including by leaving their ships in port. Furthermore, the mere capability to mine effectively may be enough to cause enemy forces to choose not to challenge a declared minefield that may have no actual mines.

Commanders must decide what type of minefields to use to obtain their operational objective. Captain Wayne P. Hughes, USN (Ret.), of the Naval Postgraduate School points out that mines can act both to attack enemy commerce and to defend our own commerce, particularly in antisubmarine warfare, in a number of ways.

1. "Ensure safety of goods and services: navies protect the *movement* of shipping and means of war on the oceans and safeguard *stationary* forces, to include nuclear-powered ballistic-missile submarines (SSBNs) and coastal patrols."
2. "Deny safety of enemy goods and services: navies prevent the movement of enemy shipping and means of war and threaten enemy forces, such as SSBNs."[11]

DEFINING THE OPERATIONAL OBJECTIVES

In many regards, the principles of maritime mining are similar to those governing the use of obstacles, barriers, and mines in land warfare. Objectives such as *disrupt, fix, turn,* and *block* are pursued both on land and at sea. However, current Navy doctrine chooses to provide specific effects rather than leverage sets of effects for communication. For example, Navy mine policy specifies that mines be usable to “deny the enemy the ability to carry out amphibious operations, or in support of friendly amphibious operations, or to destroy enemy ships and submarines directly.”[12]

The different policy descriptions can be harmonized, however; by incorporating specific effects within sets of effect terms (such as *block, fix, turn,* or *disrupt*), the planner gains a clearer understanding of how to achieve the specific policy. Yet while recognizing the numerous technical distinctions between naval and land warfare, the Navy might benefit from treating specific effects as subsets within sets of effects. This matter of deciding how to join sets and subsets may seem like a chicken-and-egg discussion; the key point is to have a method that describes the objectives sufficiently for commanders and their staffs to go beyond consideration of specific examples of maritime mining to incorporate maritime mining within operational art. For example, a minefield established with the intent to harass, deter, or send a political message would fall under the *disrupt* objective, while the intent to cause a delay long enough to allow delivery of a strike package could fall under the *fix* objective.

To derive the definitions used here for operational objectives, I extended those found in Marine Corps doctrine to focus more on maritime mining.[13] Conceptual examples follow the definitions, with historical references provided to clarify interpretations of those definitions. Concepts also are derived from *Barriers, Obstacles, and Mine Warfare for Joint Operations,* Joint Publication 3-15.[14] The examples discussed below do not cover the full range of intent, but rather provide a framework for how to categorize intent.

Disrupt

Definition. When a minefield is used to alter enemy formations and tempo, interrupt enemy timetables, cause the enemy to begin mine countermeasures (MCM) operations, or some combination thereof.

Conceptual Examples. (1) A defensive field that causes enemy formations to channelize through the field, to where hunters wait for them on the other side. (2) An offensive field designed to delay the resupplying of enemy ports.

Historical Example. During World War II, the maritime mining of Siamese (Thai) waters by the United States disrupted Japanese supply chains anywhere from a day to a month, which degraded the supply line for the Japanese army.[15]

Fix

Definition. When a minefield is designed to slow or stop targets to create a target-rich environment for friendly forces in an engagement area. Ideally, this field would inhibit the enemy’s capability to defend itself against friendly forces.

Conceptual Example. Mining a port to delay the departure of targets of interest, with the intention of sending in an air strike.

Historical Example. During World War II, thirty-two Japanese ships were trapped in port at Palau, providing a target-rich environment for Allied aircraft attacking with bombs and torpedoes.[16]

Turn

Definition. When a minefield is intended to divert enemy formations from their intended transit onto one that is advantageous to friendly units.

Conceptual Examples. (1) Turning enemy forces toward an engagement. (2) Turning enemy forces so as to increase the length of their transit routes, thereby preventing them from having adequate time in an operational area.

Historical Example. During World War I, the Dover Barrage forced U-boats to travel around a minefield, which reduced their time in their operational areas, and therefore their ability to interfere with Allied vessels.[17]

Block

Definition. When a minefield is emplaced to stop maritime traffic along a specific avenue of approach. Blocking minefields should be able to withstand enemy MCM techniques, including clearance through attrition, using creativity, technology, mine density, or some combination thereof to overcome enemy efforts. While all minefields can be integrated with joint/integrated fires, blocking minefields benefit the most.

Conceptual Examples. (1) An offensive minefield whose purpose is to close an enemy port for some duration of time. (2) A defensive field that is used to prevent an amphibious landing by the enemy.

Historical Example. The mining of Haiphong Harbor during the Vietnam War stopped all shipping even before the minefield was actually live. Sea traffic did not resume until after the U.S. Navy cleared the minefield.[18]

The maritime mining terminology currently in use provides the general location of a minefield. *Offensive* minefields are located within twelve nautical miles of the enemy's coastline. *Protective* minefields are located within twelve nautical miles of a friendly coastline. *Defensive* minefields are located more than twelve nautical miles from land.

PREPARING TO MEET REQUIREMENTS FOR OPERATIONAL OBJECTIVES

What impact on the target must be accomplished to meet the commander's intent? Three levels of damage frame intent: *mobility kill, mission abort,* and *destroy*.

Mobility kill constitutes damaging the target so that it loses the ability to control speed and heading. *Mission abort* is defined as damaging the target such that it is not capable of exercising some set of predefined capabilities. *Destroy* means to damage a target so that it sinks.

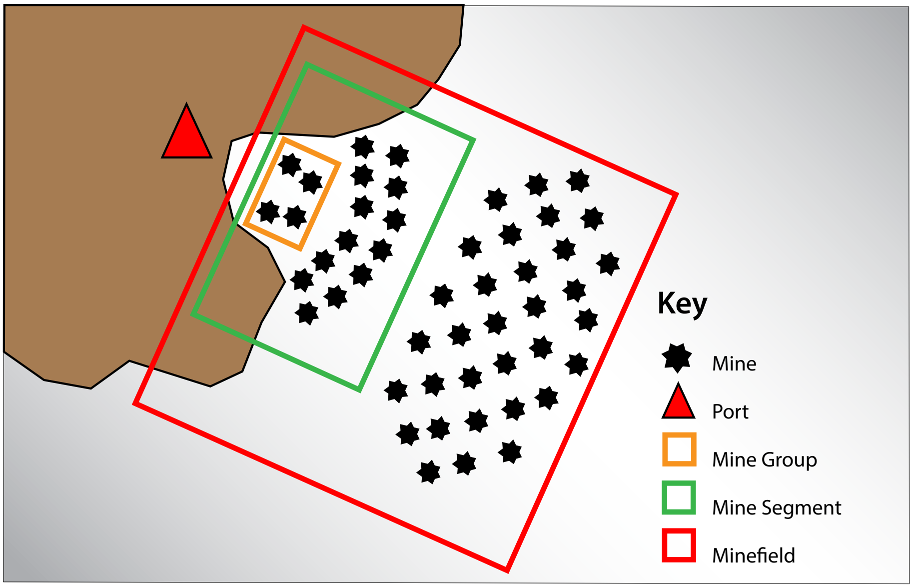
Begin by assuming that the number of mines in a field may vary on the basis of the level of damage required. (This is not the rule itself, but a framework for conveying the concept.) Hold weapon, target, and conditions constant. In this conceptual scenario, a planner would need x number of mines for *mission abort,* but may need $x - k$ mines to achieve *mobility kill* and $x + k$ mines to *destroy*. Why does this matter? If the commander intends to block a port with an offensive minefield that is not in any of the engagement areas, planners could elect to design fields to cause *mobility kills* that will prevent adversary vessels from reaching their patrol or engagement areas. Saving the k mines thus not needed (given that k might represent only one mine—or a hundred) may reduce the risk to delivery platforms, or reduce the number of weapons required to meet the MOE, or both. In another situation, a defensive field might be designed to *disrupt* within an engagement area, with the planner choosing to aim at *destroy* or *mission abort* to achieve the commander's intent. Simply put, planners should have the capability to match a desired level of damage to the operational objective.

Minefield planning relies on understanding weapon-to-target matching, yet it maintains some characteristics of an art, in that it must account for the psychological perspectives of those subjected to the mining; both aspects will dictate the planner's course of action. Commanders and planners must remember that the psychological aspect of mine warfare is often its greatest strength; therefore they should exploit the fears of the enemy creatively. However, planners should start from some core ideas, on which they can expand as needed. I offer the definitions of key terms below as such a starting point. (They assume the capability to plan and deliver precision-placed mines.)

- *Mine group:* A set of mines placed to provide a layer of threat to a target. The mine group need not be linear. The advent of precision-placed mines will provide planners the ability to plan randomly, semirandomly, linearly, or with optimized precision. Planners can create all types of patterns, although for ease of illustration this article uses mine groups with linear patterns.

- *Mine segment:* A collection of mines that are associated with each other according to conditions that impact performance. Mine segments can exist within a mine group or can consist of one or more mine groups. Figure 1 provides an example of multiple mine groups making up a mine segment, while figure 2 provides an example of a mine group that is segmented.

FIGURE 1
MULTIPLE MINE GROUPS WITHIN A MINE SEGMENT



- *Minefield:* A composition of one or more mine segments that are implemented to achieve a specific operational objective. Minefields and segments are planned to meet an appropriate measure of effectiveness. Multiple minefields might be required to achieve the operational objective.

FIGURE 2
SEGMENTED MINE GROUP

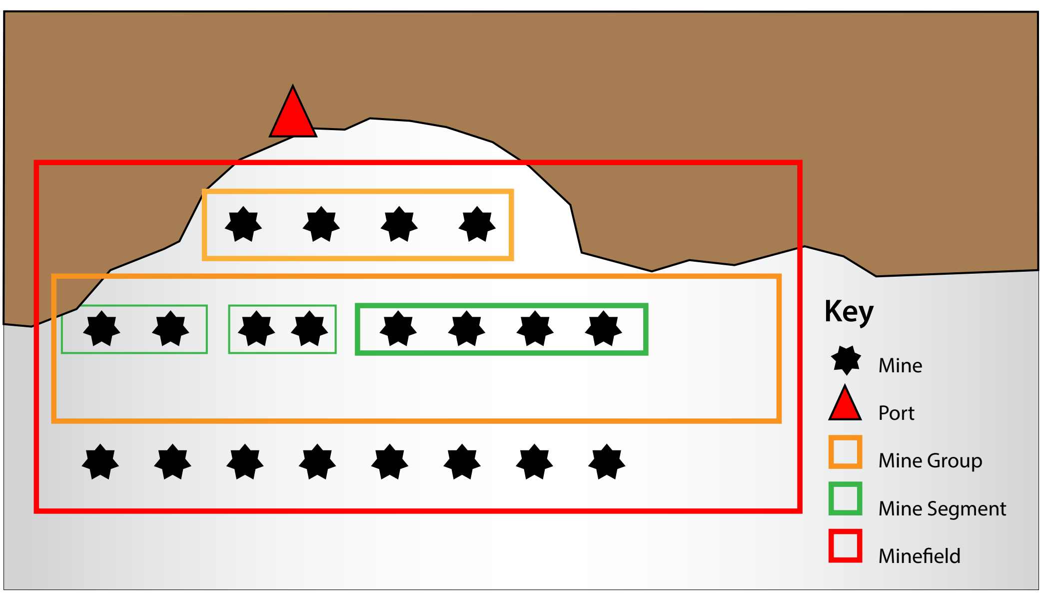
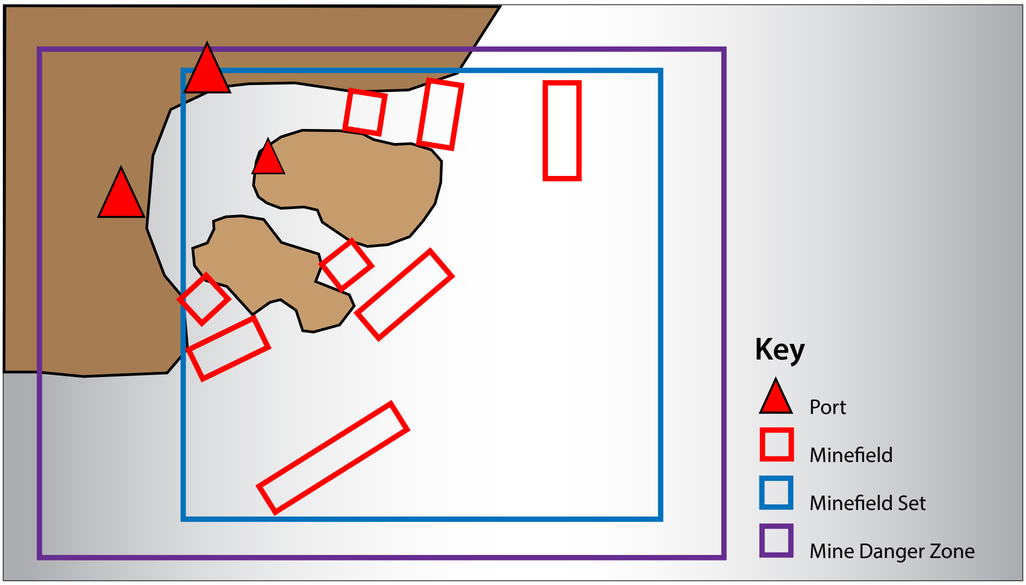


FIGURE 3
LAYERED MINEFIELDS WITHIN A MINE DANGER ZONE



- *Layered minefield:* The design of a single or multiple minefields where the target is expected to pass through more than one mine segment or minefield. The purpose is to understand the cumulative threat to the target.
- *Minefield set*. A group of minefields used to achieve an operational objective in a specific area.
- *Mine danger zone:* An area that is declared—in accordance with the Hague Convention of 1907—to alert vessels that the designated area might contain maritime mines and that safe passage within the area may not be possible.[19]

Figure 3 is a graphical depiction of the concept of layered minefields. Ideally, the minefield would be planned to meet the desired level of damage and threat to a target. The minefields then would be layered to meet the desired operational objective.

PLANNING TO ACHIEVE AN OPERATIONAL OBJECTIVE

Mine groups should be layered within the mine segment to build an appropriate level of threat within an area of the minefield. The two concepts that apply are the density of the mine group and the number of mine groups needed within a minefield to achieve the *disrupt, fix, turn,* and *block* functions. The psychological condition of the enemy and its willingness to accept risk will determine the number of minefields and the density required to meet the commander's intent. The enemy's exact psychological status may not be known until the war is over;

however, trends, status reports, and military judgment can provide enough information to deploy an initial minefield, one that later can be reshaped or reseeded to strengthen it. A single sparse minefield might be sufficient to achieve the *disrupt* and *fix* effects, whereas robust minefields may be needed for successful *turn* or *block* functions. The number of possible targets in the area will impact the number of rows of mine groups or minefields needed to achieve the desired effect. Figure 4 shows a notional guidance to communicate concepts of application.

Although there are exceptions, *disrupt*-type fields typically will be constructed from mine groups consisting of fewer mines than would other types. Such minefields will have fewer mine rows. A notional example is a minefield made up of two rows of mine groups, with each mine group presenting a threat level of *x*. Even though a *disrupt* field should require fewer mines, since it is not designed to blockade a port, an enemy may choose not to challenge the field, effectively making the *disrupt* field a *block* field.

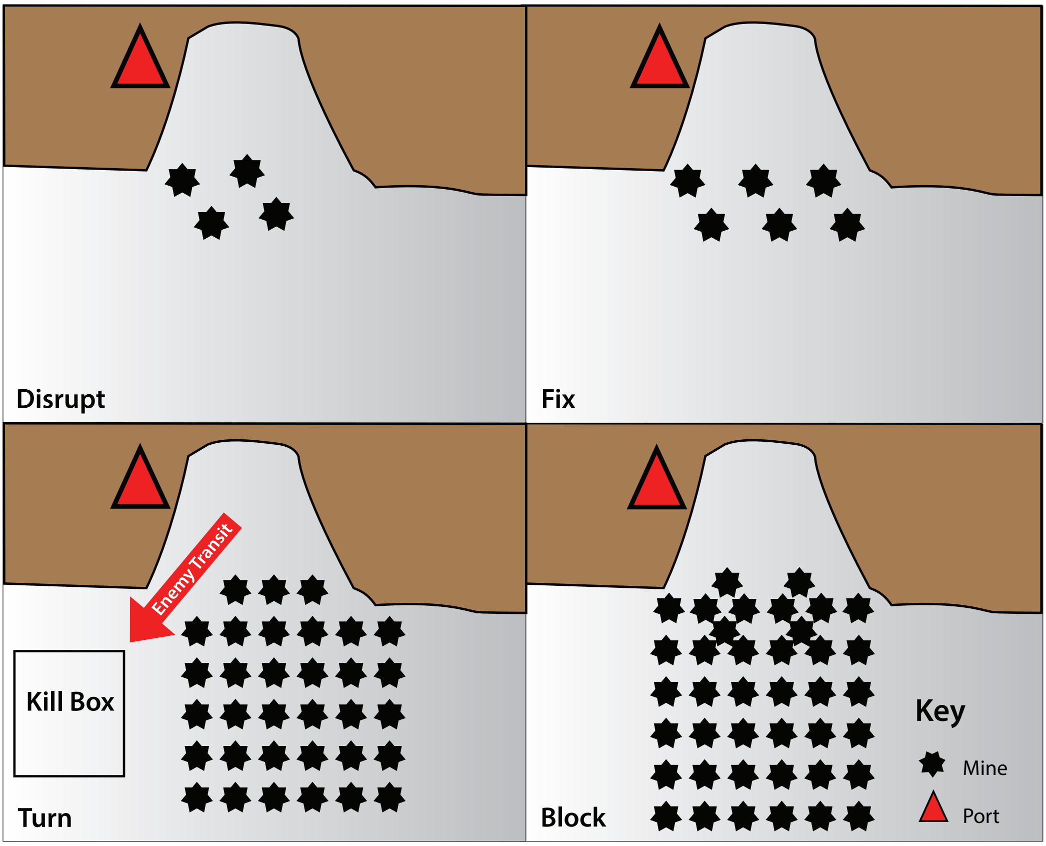
Fix fields should have mine groups that provide a somewhat higher threat level than *disrupt* fields, to extend the delay time for strike missions by increasing the risk of mine-to-target interactions or to complicate enemy MCM efforts further. Yet *fix* fields will have the same, or a similar, number of rows of mine groups within a minefield. A notional example is a minefield made up of two rows of mine groups, with each mine group providing a threat level of y, where $y > x$, with x being the threat of a *disrupt* field.

Turn fields should have mine groups providing a significant threat and a large number of rows of mine groups. This increase in threat, along with the depth of the field, should represent enough risk to the enemy that it would rather run the risk of what awaits its ships through the turn than risk a continual transit through a field it cannot counter, owing to limitations in time or technology. A notional example is a minefield consisting of six rows of mine groups, with each mine group having a threat of z, where $z > y$, with y being the threat of a *fix* field.

Block fields should have mine groups providing a significant threat and a large number of rows, as well as some additional mines seeded to account for enemy persistence. The goal is to make transit through the minefield so perilous that an enemy refuses to challenge the field. However, complete and long-term *blocks* may be nearly impossible to achieve, depending on what attrition rates the enemy will accept. A notional example is a minefield consisting of six rows of mine groups, with each mine group having a threat of $z + k$, where z is the threat of a *turn* field and k represents the additional mines added to the minefield.

Figure 4 is merely illustrative; the mine groups might be consistent or inconsistent in their placement on the basis of length. A minefield planner will exercise knowledge and creativity to determine where the individual mines should be placed. The figure provides an example useful for introducing concepts for

FIGURE 4
CONCEPTUAL MINE REQUIREMENTS PER OPERATIONAL OBJECTIVE



discussion. However, its primary purpose is to clarify terms, not to limit mining to ports; the same paradigm can be applied across maritime mining concepts.

PAIRING OPERATIONAL OBJECTIVES WITH MEASURES OF EFFECTIVENESS

It is critical to pair operational objectives with appropriate MOEs. While *simple initial threat* is a good MOE to use for *disrupt,* and possibly *fix,* fields, it is a poor measure for establishing how many mines are required to *block* a determined adversary, because it does not take into account mine attrition resulting from strikes and MCM activity. Instead, *penetrator distribution* and *expected casualties* (described below) would be suitable MOEs for the *block* function. Commanders must be able to articulate their intentions via pairing an operational objective with an MOE, such that clear communication occurs throughout the chain of command.

New MOEs also are needed—MOEs that fit with operational objectives. Otherwise, we end up forcing an MOE into an operational objective because it is merely the best fit from within the current list of MOEs. Condensed definitions of MOEs and suggestions for pairing current MOEs with operational objectives are given below; however, current MOEs were not designed specifically to meet the operational objectives discussed.

It is also necessary to note that casualties are not always the best criterion for analyzing minefield success. For example, assume that in areas A and B a planner needs to achieve a *turn,* and uses *cumulative casualty distribution* to plan the minefields. In area A, the enemy chooses not to challenge the minefield and turns accordingly—thus, the minefield does not cause a single casualty—whereas in area B, the enemy chooses to challenge the minefield and loses three ships, but does not turn and is able to move forward. Considering the loss of enemy ships, one might conclude that area B was more effective; however, area A actually was more successful at supporting the strategic objectives for the conflict. This line of analysis demonstrates that new MOEs must be developed not only to match the intent of the commander's operational objective correctly but also to broach a discussion about new MOEs for future mining capabilities. Table 1 provides

TABLE 1
DESCRIPTORS OF CURRENT MOEs

MOE	Descriptor
Time	Two measures of time: (1) the effective life of the minefield (2) the time required to execute the specified mining mission
Risk	The threat level of the minefield to enemy transitors and the risk to friendly transitors (active mines that lack remote command and control are a risk to both enemy and friendly forces)
Initial threat	The probability that the first vessel to attempt transiting through the minefield will become a casualty
Casualty density distribution	The probability that exactly *k* casualties will occur in *n* transit attempts through the minefield
Threat profile	The minefield threat to each successive transitor in a sequence of *n* transit attempts through the minefield
Expected casualties	The average number of casualties, *k,* in a given number of transits, *n,* through a minefield that would occur in a large number of repetitions of *n* transit attempts under statistically equivalent conditions
Cumulative casualty distribution	The probability of at least *k* casualties out of *n* transits through the minefield
Sustained threat	The measure of a minefield's ability to resist the effects of enemy mine countermeasures and provide a continued threat following passage of the first enemy transitors
Penetrator distribution	The probability of exactly *j* penetrators (targets that safely transit the minefield) in *n* transit attempts through the minefield

TABLE 2
RECOMMENDED PAIRINGS USING CURRENT MOEs

Operational Objective	Applicable MOEs (*time* and *sustained threat* are implied considerations throughout)
Disrupt	*Initial threat*
Fix	*Initial threat* Low levels of *expected casualties, cumulative casualty distribution, penetrator distribution*
Turn	High levels of *expected casualties, cumulative casualty distribution, penetrator distribution*
Block	Highest levels of *expected casualties, cumulative casualty distribution, penetrator distribution*

descriptors of current MOEs; table 2 provides recommendations for matching them to objectives.

The methodology used pairs the operational objective with the current MOE that best suits the intent of the operational objective. For example, if the intent is to *disrupt* an enemy, the best MOEs to use may be *time* and *initial threat,* because of the relative amount of investment required to achieve the desired effects. If the intent is to cause an enemy to delay the departure of his assets and force him to conduct MCM, merely causing him to perceive some threat may delay the departure of ships and bring on MCM operations. This may be achieved via an *initial threat* versus a *penetrator distribution,* which might obviate the need for a massive investment, depending on the choices made for the *j* penetrators out of *n* transitors.

WHY IT MATTERS

The mine warfare community is small; it lacks the exposure and training afforded to many other warfare areas. This has decayed the understanding and valuation of the U.S. Navy's mining capability, which then compounds the exposure and training deficits. This result further complicates matters through a loss of appreciation for the painstaking process that minefield planners must complete to continue to provide sound plans.

Having clear operational objectives and their associated MOEs linked together will provide decision makers with the information necessary to match each MOE to its desired effect. The question of what *simple initial threat* is needed to blockade a port is a difficult one even in a specific context, especially when even the threat of a minefield may blockade a port. However, until we fully understand the psychology of our adversary—a daunting proposition—it is clear that we must look at more-appropriate MOEs to achieve a blockade. Effective mining is achieved through clear operational objectives, MOEs, training, planning tools, and effective delivery. Tools and training should be developed to optimize what can be delivered, considering the dynamics of conflict.

THE MINES OF TOMORROW

During a November 2015 Mine Warfare Association event, Expeditionary Warfare (OPNAV N95) discussed several efforts to advance the capabilities of maritime mining. The current mine inventory is seeing new algorithms and increased capabilities. Some of the mines of tomorrow will be delivered from unmanned underwater vehicles equipped with large-diameter tubes. Technological initiatives are striving to create precision mining with standoff for air-delivery platforms; other efforts include remote-control capability and wide-area coverage.[20] Open-source literature gives us a glimpse of possibilities, starting with the next iteration of air-delivered mines.

Precision air-delivered mines for use at standoff ranges are being created from mine components that are already in the U.S. inventory. Efforts to provide mines with the same splash-point accuracy of a Joint Direct Attack Munition are under way through Quickstrike-J. To expand further the capability of precision air-delivered mines, efforts to extend ranges also are moving forward with Quickstrike-ER. Success will allow a B-52H to lay an entire minefield in one pass, without having to fly over the minefield, while achieving mine-placement accuracies within six meters of aim points on the seabed.[21]

Smart mining will provide commanders with wide-area-coverage minefields, positive control of the minefield, and the ability to engage multiple targets that use the same transit path. Unlike traditional minefields, a single weapon-to-target interaction does not cause a hole in the minefield (assuming that there is more than a single weapon); thus, a persistent threat to traffic will remain despite adversary efforts to channelize traffic to minimize traditional mine engagements.

McGeehan and Wahl call for the use of underwater gliders to carry guidance and trigger systems and explosives—effectively, to convert them into smart mines. Their concept calls for using “flash mob” tactics: mobile mines converging on shipping lanes and choke points, or simply creating a barrier. These mines would be able to avoid mine countermeasures while waiting for instructions. Furthermore, such a concept would allow friendly units to pass through safely, with the barrier reestablished behind them. New effects also are being introduced to detain ships by fouling props and rudders, or disabling them by other nonkinetic means. Using nonlethal mines would allow the neutralization rather than the sinking of targets—to enforce an embargo, for instance.[22]

The United States is not the only country interested in using mining to reduce the capabilities of potential adversaries. According to GlobalSecurity.org, Iran can produce nonmagnetic, free-floating, and remote-controlled mines.[23] Furthermore, it also may have acquired mines from Russia and negotiated for rocket-propelled rising mines from China. In another example, Goldstein provides evidence that China views maritime mining as an important component of naval warfare.[24] Its concepts for mine delivery include air, surface, and subsurface platforms that can deliver mines so as to provide challenges in both ports and open water. Mining is such a key component for China that fishing vessels may be called on to "block foreign enemy intervention." To counter our surveillance, MCM, and antisubmarine warfare capabilities, China also is looking at emerging technology to target aircraft, using mines that launch missiles. Truver further describes China's mining capability, mentioning that the country has more than thirty types of mines, including remote-controlled, rocket-propelled, and mobile varieties.[25] Several other countries' capabilities in maritime mining are progressing, and it would be a mistake to think they are looking only at traditional measures.

MINEFIELD PLANNING CAPABILITIES

Pietrucha points out that advances in mining technology are outpacing the capacity of planners to design minefields properly. As new maritime mining capabilities are added, the tools and concepts of mine warfare should evolve to maximize the effectiveness of the new maritime mines.[26] This is particularly important with regard to the emerging capabilities of the Clandestine Delivered Mine System (in which unmanned vehicles deliver mines) and the new Quickstrike-J/ER mine (which will be in service shortly), followed by other advanced mining concepts.

Initial threat is determined with regard to the minefield as it exists before an enemy attempts to challenge the minefield. After the initial target-to-weapon engagement (particularly in cases involving explode-in-place mines) the threat level is changed, because the minefield itself is no longer the same. A new analysis would be needed to determine the threat that the remaining mines represent. In some cases, planners and operational leaders themselves—especially those unfamiliar with mining—may not understand the reduction in the threat that the revised field poses, and may assume that the initial threat is sustained for each target. Such an interpretation might lead to operational or tactical miscalculation, perhaps with catastrophic results. On the other hand, mining concepts based on weaponized distributive sensor nodes may mean that the threat will be consistent for each target until weapon depletion, assuming the field is planned to engage each target.

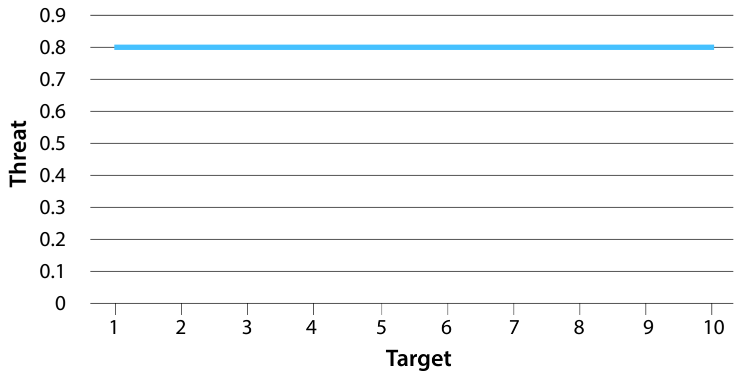
Minefield planning capabilities and language must be created to enable planning for and communicating about future minefields, especially those involving precision placement. For instance, planners should be able to convey plans readily for various traffic patterns. This is particularly important for fields in choke points (for *cumulative casualty*–type measures) and open-water fields (in which targets might advance in a spread formation, enabling the minefield to interact with multiple targets at once). It is possible simply to add terms to current and future minefield plans to differentiate the assumptions. Examples include *channelized cumulative casualty distribution* and *random cumulative casualty distribution,* where *channelized* and *random* are meant to clarify assumptions about the targets' behavior through the minefield (*channelized:* targets enter the field in a line; *random:* targets enter the field at random locations). Effective language is needed to communicate the specifics of fields that soon may be constructed using a greatly expanded list of effectors, and this language should be incorporated into the planning tool.

MINING MEASURES OF EFFECTIVENESS EXPANSION

While operational objectives are critical to any strategy, it is important for mine planners and commanders to have something against which to measure their fields. While the MOEs now in place measure current capabilities adequately, emerging mining capabilities will require new MOEs to assess their effects. In the discussion below I identify concepts for MOE expansion to meet the upgraded capabilities of today's mines, as well as those of tomorrow.

The first is *continuous threat*.[27] The premise is to plan fields for a threat level for *n* number of targets, given *k* number of effectors. (For now, explosive effectors that engage one target will be the focus, but the Navy also is assessing various other effectors, both kinetic and nonkinetic.) Essentially, *continuous threat* means being able to maintain *simple initial threat* for a determined number of follow-on targets. For example, the *simple initial threat* may be *x* for the first targets, then be lowered to *y* for the next, while *continuous threat* maintains the threat of *x* for various targets. Planners would be able to incorporate effectively targeting optimization, counters, probability of fire, delay arm, and other capabilities early on in the planning process to determine the resources required to create the ordered field. Furthermore, with the ability in the near future to practice precision placement of mines and to combine that with some degree of positive control of the minefield, the command and control authority should be able to check the "health" of the field and maintain it by reseeding mines or reshaping the field. This should permit the authority to limit the number of sorties required to ensure that the field maintains its designed threat level right up until the field can no longer achieve the intended threat level or is depleted of effectors. While a number of factors dictate the threat the field represents, the premise is to maintain the threat against multiple targets, regardless of what formation or channelization they choose. This MOE is particularly relevant to weaponized distributive

FIGURE 5
CONTINUOUS THREAT



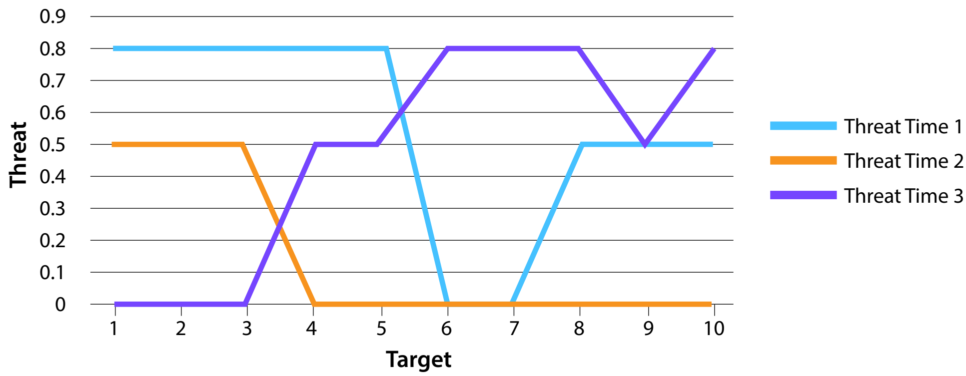
This graphic communicates the idea that a threat level can remain the same for targets until the system is no longer capable of maintaining threat—e.g., all weapons are expended.

sensor–type mining systems. *Continuous threat* is one of the small number of MOEs that should fit under any of the operational objectives.

A natural extension from the *continuous threat* MOE is the *threat over time* MOE. The concept is that commanders would be able to implement threat to *n* targets per day (or some other time measure—e.g., hours) for a desired duration. The idea is to optimize systems so as to vary threat level *t* for *n* out of *k* targets per day over some duration of time. This MOE may be used to highlight specific times of interest, such as high tide; reduce threat during low tide; or simply exercise a variable threat throughout the time. Planners can employ this MOE with creativity to achieve their objectives. The *threat over time* MOE lends itself to forecasting reseeding requirements, which would assist with asset and supply planning, as well as providing considerations for repositioning planning (shoot and relocate, shoot and withdraw) for self-relocating effectors and effector/vehicle minefields or applications of remote command and control with explode-in-place mines. This MOE would fall under the *disrupt* and *fix* operational objectives.

Extensions of the current *time* MOE might capture *estimated time of operational effect*. Extension becomes necessary when, for instance, a minefield is still active even though it no longer can achieve its original intended objective. The MOE would be based on mixed-method analysis from known capabilities and military judgment, refined as information and intent change throughout the conflict. This MOE inherently suffers from numerous sources for error; however, it also has the potential to provide an answer concerning time. For example, consider the commander's operational objective of *blockade,* intended to close a port. While the ability to execute a mining mission is critical, the importance

FIGURE 6
THREAT OVER TIME



The figure abstractly communicates the potential to vary threat to different targets across some length of time. For instance, Time 1 may be a single day, with consistent threat for the first six targets *(n)*, then varying threat levels *(t)* over the *k* targets with respect to time. Multiple threat times are depicted to address the flexibility of the time scale: weeks, days, hours, etc. Time 2 demonstrates threat during a specific time, such as high tide. Time 3 shows the potential for variation across targets over time.

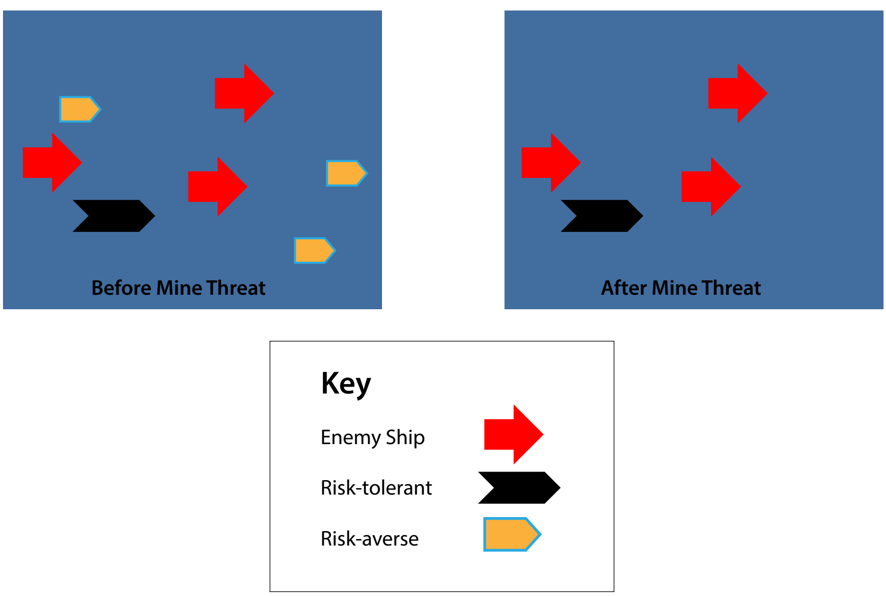
of the amount of time the field will be operationally relevant should not be lost; thus, the commander will want to know the best estimate for the length of time the field will be able operationally to support the strategic objectives of the fleet. Providing this answer requires combining multiple variables into a "best estimate." Answering the commander's important question—"How long?"—will require a range of subject-matter experts to assist the planner in assigning values to these variables. The first variable is the *initial threat of the field* needed (with counter-countermeasures already defined) to cause the enemy to perceive threat in the port. The second variable is the enemy's *acceptable attrition rate*—that is, what level of casualties he is willing to accept to challenge the field (including with hardened vessels or those that choose to disregard the risk) before conducting professional MCM. Essentially, this variable captures what attrition the enemy considers acceptable in attempting to open a channel via brute-force port breakout.

The next variable considers enemy MCM. To calculate its value, intelligence officers will determine how important the port is relative to other ports, the enemy's order of battle for clearing fields, where those credible enemy MCM assets are located, and how long it will take for them to transit to the port of interest. Assigning a value to this variable will require assistance from MCM experts and intelligence officers. MCM experts will use software tools (such as the Naval Mine Warfare Simulation) to determine how long it will take to clear a channel through the field. Intelligence officers will estimate the enemy's level of acceptable risk, as well as an MCM skill multiplier that compares the enemy's abilities with our own, based on trends and other sources of information. Once these values are determined, the planner can create a minefield calculated to provide an *estimated time of operational effect*. Like *continuous threat,* this MOE will fit under any of the operational objectives.

The final MOE offered is *scalable traffic*. While this MOE can have direct military application, it mainly is intended to support political and economic impacts. Ideally, this MOE would be associated with a mine that is highly reliable and has an efficient discrimination capability. Examples of military applications include forcing the enemy to change his replenishment behavior and reducing traffic in an area to increase the probability that a given vessel in the minefield is a desired target. Achieving a political/economic impact would require knowing, or estimating with some appropriate level of confidence, what level of threat would be needed to deter noncombatants from entering an area of interest. This MOE would require initial research efforts to provide an estimate of likely courses of action from military, commercial, and private vessels that commonly operate within an area of interest. This MOE would allow commanders to employ the minimum number of mines required to change the traffic of vessels in specific categories.

However, planners' capacity to map with this ability in mind requires conducting research and considering trends amid circumstances that may be in flux. For example, assume that the objective is to stop a particular shipping company from delivering particular items to a port. Investigation has indicated that the company

FIGURE 7
SCALABLE TRAFFIC



This graphic showcases how traffic density can decrease on the basis of levels of mine threat. This reduction of traffic improves the engagement environment, reducing the probability of unintended tracking and collateral damage.

is not highly motivated to risk damage—entering a minefield would cancel its insurance policy. This consideration disrupts the delivery timetable. However, some companies or state-sponsored ships might be willing to challenge the field, owing to a monetary or other kind of inducement promised for undertaking the challenge. The research should attempt to determine how much risk or attrition would be sufficient to convince all comers that the risk is not worth the reward. While one minefield may turn away ships in one group, an increased threat or level of attrition might be required to turn away those in another group. Furthermore, knowing how traffic should react provides planners with a starting point for selecting mine counter-countermeasures and provides some indication of the probability that the vessels within the minefield are targets of interest. Reducing the density of nontargets within an area lowers the likelihood that unintended targets will be tracked or hit, and provides warfighters with a clearer picture of the battle space. The concept even might be applied in the form of announcing a fictitious or phony minefield in an effort to reduce traffic so as to provide submarines a clearer area of operation. This concept also can be applied to the goal of diverting traffic. *Scalable traffic* could fit under the operational objectives of *disrupt* and *turn*.

Current mining paradigms and shape concepts must be improved to prepare for the mining of the future. Doing so will require creating categories of operational objectives to assist commanders and planners in clarifying intent. The ability to plan for various effects on a target (e.g., *mobility kill,* particularly when nonlethal mines are operational) will allow planners to recommend options that could achieve the intent while possibly reducing the number of mines required to complete a mission. Such a reduction in mines likely would reduce costs, in terms of both risk and inventory. Linking operational objectives to MOEs will provide warfighters with a clear understanding of what type of effort must be carried out to realize the commander's intent. Investing in new minefield planning capabilities and MOEs will enable the fleet to capitalize now on emerging capabilities even as they prepare for mid- and long-term capabilities. It is critical that the concepts, language, support, and tools for the mines of tomorrow keep pace with the development of those mines.

Table 3 shows what tomorrow's MOE pairings may look like.

Commanders and planners would be able to discuss varying levels of threat to the target and would have a clear starting point for discussing objectives and measures. Neal Kusumoto has written: "The real success of mining is often indirect and usually difficult to measure. The operational artist is faced with the choice of either building an MOE with his situation's strategic and operational objectives clearly in mind, choosing one of the existing MOEs knowing its

TABLE 3
POSSIBLE PAIRINGS USING FUTURE MOEs

Operational Objective	Applicable MOEs (*estimated time of operational effect, time,* and *sustained threat* are implied considerations throughout)
Disrupt	*Initial threat, continuous threat, threat over time, scalable traffic*
Fix	*Initial threat* Low levels of *expected casualties, cumulative casualty distribution, penetrator distribution, continuous threat, threat over time*
Turn	High levels of *expected casualties, cumulative casualty distribution, penetrator distribution, continuous threat, scalable traffic*
Block	Highest levels of *expected casualties, cumulative casualty distribution, penetrator distribution, continuous threat*

limitations, or assuming a certain level of effect."[28] While the MOEs suggested in this article certainly do not encompass all those needed, a conversation should begin now regarding investment of the time necessary to update doctrine. This may relieve the pressure on some future planner attempting to match intent with MOEs during a conflict, allowing him or her to focus on the actual plan instead.

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