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SET AND DRIFT

— I —

What Is Command and Control Warfare?

Lieutenant Commander Dan Struble, U.S. Naval Reserve

COMMAND AND CONTROL WARFARE (C2W) has rapidly become the central idea in the American approach to waging war. C2W reflects a change in the way commanders are to think about, organize for, and conduct combat operations. It affects the actions of combatants at all levels, in that it demands coordination—in the use of information and in precision of action—to a degree never before expected or possible in warfare. In the last two years, a whole new set of terms and concepts have been introduced to the armed

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forces. A revolution in warfare is occurring, and today, as is only to be expected, a certain amount of confusion exists. The purpose of this essay is to make sense of, and put into perspective, the bewildering changes that C2W requires of the United States military.

Depending on the context in which one first confronts C2W, one might consider it a policy, a strategy, a doctrine, a subset of Information Warfare, a set of renamed shore commands, a new primary commander within the Navy's Composite Warfare Commander doctrine, or a mish-mash of new terms.[1] Furthermore, one cannot delve far into C2W before confronting security classification obstacles.[2] However, like the proverbial elephant examined by a group of blind men, this confusing array of changes does makes sense when viewed from the proper perspective. Conceptually speaking, C2W is not difficult to understand and does not require access to classified information.

C2W is in fact all of the things listed above, and more. First and foremost, it is the *result of* (not the cause of) a paradigm shift that has had technological, organizational, strategic, and policy significance. A paradigm shift is a change in the way one thinks about things—in this case, the assessment of tools and their employment for waging war.

Much as blitzkrieg altered the world's evaluation of the tank and became the prototype of maneuver warfare, Desert Storm has become the prototype of command and control warfare. Desert Storm changed how tomorrow's commanders must think about warfare. Desert Storm commanders—in addition to simply destroying enemy command facilities, communications nodes, and sensor installations—made good use of operations security, military deception, psychological operations, and electronic warfare in order to prevent Iraqi leaders from effectively employing their own forces. These five tools, mutually supported by intelligence, have become known as the "pillars" of C2W.[3] Their coordinated use to keep an enemy from successfully operating his forces, though it has by no means replaced the option of direct defeat of an enemy's combat elements, has supplanted the primacy of that approach.

"Command and Control Warfare" is the label the Joint Chiefs of Staff have applied to this new way of thinking about the employment of armed force; new policies, doctrines, commands, and terminology are the means by which this paradigm shift is being institutionalized. Institutionalization is necessary if the hundreds of thousands of individuals within the U.S. military are to reorient their behavior and thinking. The message being conveyed to them is that defeating the enemy's ability to employ force is a more effective way to prevail than destroying the force itself.

Technology and C2W

While Desert Storm was a military victory of truly historic proportions, the tools, concepts, and tactics now associated with C2W emerged earlier. Desert Storm was the watershed event, in which tools and procedures that had been developing throughout the armed forces were brought together and employed in a striking new way.

Technological developments made the shift in emphasis possible. The development of tools to aid in the collection, processing, evaluation, and communication of information—tools that were making possible the so-called "information revolution" in modern society—allowed commanders at all levels to exercise more timely and effective control over their forces. Technology made it possible for them to create a better picture of the "battle space," to understand more clearly where force can be decisive, and to control more precisely the application of that force. Concurrently, the development of precision weapons technology made destruction itself a much more efficient option.

These technological developments have now made a force's command and control (C2) nodes, always vital in battle, even more important.[4] The same technologies also render these nodes more vulnerable than ever before. Improved surveillance capabilities make it more likely that C2 nodes will be identified, evaluated as to importance, and targeted. Furthermore, because effective command and control depends on the information that is received, the performance of a C2 node (or an entire system) can be degraded by way of that input. Thus, one can "target" a system without designating it for destruction; by combining operations security, military deception, psychological operations, and electronic warfare, one may completely nullify an enemy force. The key element these tools have in common is their intended target: the enemy's command and control system. C2W aims at the defeat of that system, whether by physical destruction or effective nullification.

While advances in communications and weapons technology made command and control warfare possible, C2W is not simply a by-product of them. The tank, for instance, was used in World War I, but ineffectually; its potential was fully realized only in World War II, when incorporated in the blitzkrieg. In the same way, highly sophisticated intelligence collection systems, computers, communications, and weapons have been on hand for some time. They were individually developed to improve the ability to gather information, or to analyze it, or to communicate more readily with distant forces, or to penetrate enemy airspace with less risk of detection, or to increase the probability a weapon would hit the intended target, or to counter some new weapon a potential adversary had developed, and so forth, *ad infinitum*. The contribution of Desert Storm was the synergistic employment of tools and tactics for the express purpose of neutralizing Iraq's command and control capability. The success of that effort has led U.S. military leaders to decide that future battles will be fought with a similar intent in mind—except, of course, when commanders are not empowered to engage the enemy, or against guerrilla-type opponents without sophisticated C2.

Key Concepts

It may be desirable to destroy an enemy's force, but doing so becomes a much simpler and less dangerous proposition if the enemy has been made unable to control that force. C2W, therefore, has the objective of "decapitating the enemy's command structure from its body of combat forces."[5] There are five tools formally associated with this strategy: operations security, military deception, psychological operations, electronic warfare, and physical destruction.

Operations security denies information to an enemy's command and control systems; it prevents key facts about one's own capabilities and intentions from becoming known to enemy forces until it is too late for those facts to be of use to them. Just as the timing of the first strikes on Baghdad was successfully hidden until Tomahawk missiles began hitting their targets, future military operations also must attend closely to operations security.

Through *military deception* one feeds enemy commanders information that is intended and designed to mislead them about present conditions and future activities. In Desert Storm, of course, the best-known military deception was the amphibious feint of the Marine Corps' 4th and 5th Marine Expeditionary Brigades afloat in the Arabian Gulf. To bolster this deception, a widely reported rehearsal landing was staged just weeks before the ground campaign began.

Psychological operations tell the truth in ways that make it difficult for enemy leaders to influence their forces or population as they might desire. The dropping of surrender instructions on front-line Iraqi positions is one example of this component of C2W.

The familiar discipline of *electronic warfare* is now divided into three subsets. Electronic surveillance (ES) aims at acquiring a comprehensive understanding of an enemy's electronic emissions, whether of sensors such as radars or of communications equipment, like radios. Electronic attack (EA) attempts to nullify or mislead enemy systems by such measures as jamming or imitative transmissions. Electronic protection (EP) strives to ensure that one's own electronic sensors and communications equipment are not disrupted or deceived by enemy efforts in electronic warfare. All three forms figured prominently in Desert Storm C2W.

Finally, *physical destruction*, as it pertains to C2W, refers to attacks specifically on enemy command and control assets. Tomahawk missile and laser-guided bomb strikes on communication buildings in Baghdad, the Apache helicopter attack against early-warning radar sites along Iraq's southern border to "blind" the enemy on the air campaign's opening night, and similar activities illustrate this aspect of C2W.

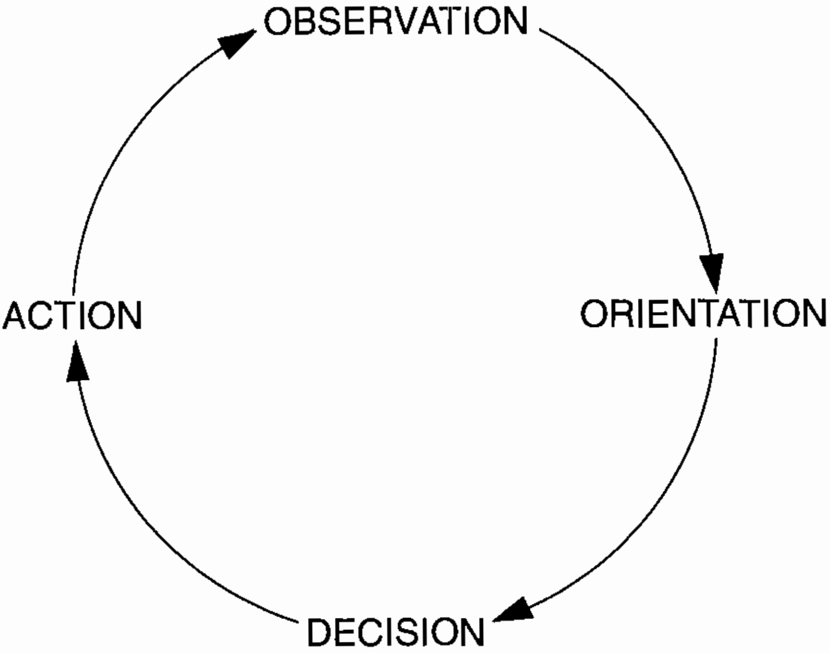
The greatest challenge of C2W is to integrate all five of these tools into a coherent whole to contribute to the commander's overall objective. One must not physically destroy an enemy sensor through which one plans to convey deceptive information, nor should one exercise strict operational security in a group conducting an amphibious demonstration far from one's actual objective. The art of C2W lies in synergistically coordinating all aspects of operations security, military deception, psychological operations, electronic warfare, and physical destruction.

Because one's own command and control systems are as vulnerable as the enemy's, and for the same reasons, C2W has two fundamental aspects: targeting an enemy's command and control ("counter-C2") and protecting one's own ("C2-protect"). The discussion so far has been directed to targeting the enemy's assets, i.e., "counter-C2"; the reciprocal threat will increase as potential adversaries grow more sophisticated, so commanders and their C2W planning staffs will have not only to prevent enemies from successfully degrading "friendly" C2 systems but to use to advantage enemy efforts to target them.[7]

A concept frequently associated with C2W is Air Force Colonel John Boyd's "OODA loop." The OODA loop represents the command and control decision cycle: *O*bservation, *O*rientation, *D*ecision, and *A*ction, arranged in a circle as depicted in figure 1. The OODA loop holds that one must observe the battle space (collect information), properly orient that information (construct a battlespace model), make decisions based on that model, and take actions to implement those decisions. Initiative and agility require that commanders go through the decision cycle quickly and effectively.[8] To prevail, however, a commander must do so more effectively and faster than the enemy. That is, in this connection, one's OODA loop must "get inside" the enemy's.

C2W promotes that end by interfering with the enemy's ability to execute the decision cycle. Operations security, electronic attack, and destruction of surveillance assets prevent enemies from observing activities and discerning real intentions. Deception gives enemy commanders a false picture and thereby degrades their ability to make appropriate command decisions. Psychological operations, physical destruction, and electronic attack and protection prevent enemy forces from taking their preferred courses of action. Each of these tools reduces the speed or degrades the effectiveness with which an opponent can go through the decision cycle.

Figure 1



The "OODA LOOP"

The obverse is a matter of increasing one's own speed and effectiveness in the cycle both by improving equipment and procedures and by preventing the enemy from interfering. "C2-protect" uses operations security, electronic attack, and physical destruction to safeguard decision processes from the enemy. Electronic protection aims at preventing the effective use of electromagnetic energy against friendly C2 systems. Finally, electronic support helps provide a clear picture of the electromagnetic battle.

The term "battle space" has been used advisedly in this discussion; it is a broader concept than the more common "battlefield," which has traditionally connoted a two-dimensional surface with topographical variations, recently stretched to three dimensions to accommodate air and underwater operations. "Battle space," however, encompasses space-based assets and the electromagnetic spectrum.[9] C2W concepts have as one of their purposes that of directing commanders' efforts toward the effective use and control of all elements of the battle space.

Intelligence and C2W

Little has been said in this essay about the place of intelligence in C2W, but it is a fundamental element of this approach to warfare. An accurate picture of the battle space would be impossible without data on the weapons of potential adversaries and without surveillance means capable of identifying critical C2 nodes. While intelligence has been a key to winning (and avoiding) wars at least since Sun Tzu aptly identified "foreknowledge" as the fundamental difference between effective and ineffective commanders, modern intelligence systems have earned the discipline a new place in warfare.

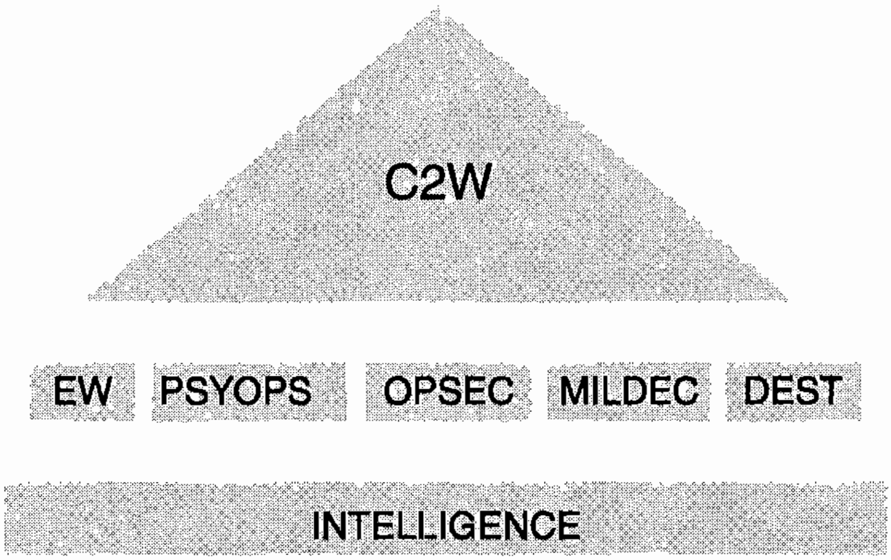
The capability to collect, compile, gain access to, analyze, and communicate intelligence information has increased exponentially with the development of surveillance, computer, and communication technology. Particularly through space-based systems and other national intelligence assets, commanders can now know almost as much about the disposition of hostile forces as enemy leaders, if not more. This information allows one to identify, prioritize, and target enemy command and control nodes (a process called nodal analysis). The five C2W tools, when used in conjunction with intelligence data in real or near-real time, can thereby be extraordinarily effective. (See figure 2.)

In the U.S. Navy, intelligence will be important to all the components of the Composite Warfare Commander organization. The role of the Command and Control Warfare Commander, or C2WC, with respect to intelligence is to sanitize and distribute information more broadly and quickly than has heretofore been the practice.[10] This role is particularly important since equipment and procedures at the national level are being improved to get data to deployed forces rapidly enough to give tactical significance to information and systems previously reserved for strategic uses.

The Navy, Space and Electronic Warfare, and C2W

C2W did not simply "appear," as if from a vacuum. In the U.S. Navy, its precursor was called Space and Electronic Warfare, or SEW. In 1988 the Chief of Naval Operations established a Radio Electronic Battle Management Review to integrate intelligence, surveillance, communications, signature management, electronic warfare, targeting, and command and control; one result was the Space and Electronic Warfare concept. Approved in 1989, it was implemented in 1990 as a primary warfare area, complete with its own commander within the Composite Warfare Commander doctrine—the

Figure 2



Space and Electronic Warfare Commander, or SEWC. The first battle group to deploy with a SEWC sailed shortly before Iraq's invasion of Kuwait; needless to say, the concept was by no means fully developed at that time, nor was the fleet practiced in its use.

The Navy continued to develop SEW concepts and tactics during and after the Persian Gulf War. In May 1992 the commanders of the Second and Third fleets issued a joint tactical memorandum on the subject, and in July 1992 the Chief of Naval Operations issued the "Navy SEW White Paper," marking "the end of the beginning." The white paper's purpose was to capture as an integral part of naval warfare the revolutionary new opportunities that had been offered by Space and Electronic Warfare. Work was progressing on an SEW "tactical notice" from the commanders in chief of the Atlantic and Pacific fleets when, in March 1993, the Chairman of the Joint Chiefs of Staff established Command and Control Warfare as a joint policy.

The Navy's prior development of SEW now placed the service, in some respects, in the vanguard of the general movement toward new approaches to warfare. Full utilization of the battle space and a target set comprising command and control assets are key elements of both the C2W and SEW concepts. But they are in fact very different approaches, and their differences have created problems. First, C2W and SEW use different vocabularies. Also, where C2W has five "tools," SEW is divided into eight "disciplines."[11] C2W is primarily, in itself, a paradigm shift; SEW incorporates that shift but emphasizes systems and technology more specifically.

In October 1993 the Navy decided to move from SEW to the C2W focus and attendant terminology. While this shift was necessary if the Navy was to continue to strengthen its embrace of joint warfare, and was likely inevitable anyway, the specific manner in which it was carried out resulted in difficulties: the Chief of Naval Operations simply directed that the SEWC be renamed the C2WC. It was done in a manner that implied that SEW and C2W were effectively interchangeable, which contributed to the subsequent confusion associated with the adoption of C2W concepts, terminology, and tactics.

Changes of this sort and magnitude always result in problems to be worked through. The Navy has had lately to make several strategic and organizational adjustments, e.g., from a focus on war at sea to littoral warfare; from the traditional bureau system to a general staff organization; and the adoption and development of Space and Electronic Warfare and, in turn, its supersession by Command and Control Warfare. Each change has been accompanied by new ideas, terminology, and organizations, all of them during a period of such radically reduced budgets that it is not always obvious whether rationales have to do more with strategy or down-sizing. It is no wonder that a time lag exists between implementation, understanding, acceptance, and effective utilization.

That lag is clearly in evidence in the fleet today. SEW terminology and concepts, themselves still not fully understood, remain in use and are confused with those of C2W. Inevitably, Navywide understanding of the latter will take quite some time. Acceptance and effective utilization, on the other hand, while requiring understanding, depend more on the decisions of service leaders. If this new approach to warfare is truly to affect operations, the structures created toward that end must be enabled to make a place for themselves among established organizations, especially in staffs afloat.

The fleet, which was asked to make two fundamental, successive, and not quite congruent conceptual leaps, now has to accomplish a highly significant paradigm shift with respect to its internal procedures before it can properly accommodate this revolutionary new approach to war, C2W.

Notes

1. "Command and Control Warfare," Chairman of the Joint Chiefs of Staff, Memorandum of Policy no. 30 (first revision) [hereafter MOP 30], 8 March 1993, was issued to "provide joint policy and guidance for command and control warfare (C2W)." The Student Text for the Joint Command and Control Warfare

Staff Officer Course at the Armed Forces Staff College calls (page 1-6) C2W an "integrated" and "supporting" strategy. Joint Pub 3-13, *Joint Command and Control Warfare*, provides C2W doctrine for joint operations and was in draft form at this writing. MOP 30 declares that "C2W is the military strategy that implements Information Warfare (DOD Directive TS-3600.1, 21 December 1992, 'Information Warfare') on the battlefield and integrates physical destruction." The Navy operates Command and Control Warfare commands in Coronado, California, and Little Creek, Virginia. Now called C2WGRUPAC and C2WGRULANT, prior to 1 March 1994 these commands were known as Fleet Tactical Deception Groups. At the joint level, the Joint Electronic Warfare Center in San Antonio, Texas, has been renamed the Joint Command and Control Warfare Center (JC2WC). It now appears that these entities will again change names, this time to "Information Warfare" commands.

The U.S. Navy's Composite Warfare Commander (CWC) doctrine structures the operational staffs of battle and amphibious ready groups, and the like, for combat: "commanders" (e.g., the Antisubmarine Warfare Commander, known as the ASWC) direct the operations of all assigned ships, aircraft, etc., in a particular warfare area; and "coordinators" allocate critical but scarce assets (such as helicopters) needed by more than one warfare commander. The function of Command and Control Warfare Commander, C2WC, was established on 17 October 1993, replacing the Space and Electronic Warfare Commander, SEWC—of which more below.

Finally, C2W replaced the use of C3CM (Command, Control, Communications, and Countermeasures) in revision 1 of MOP 30. At about the same time, MOP 6, "Electronic Warfare," was revised to rename concepts long associated with EW; see note 6, below.

2. Security classification is an obstacle to understanding C2W only when one begins to look at the specific equipment involved or goes beyond concepts to doctrine concerning intended tactics.

3. The term "tool" is more descriptive of the five elements of C2W than "pillar" and will therefore be used throughout this essay. "Pillar" is used here because readers may encounter it in other reading on this topic.

4. A "C2 node" is a physical entity within a command and control system at which are concentrated personnel, procedures, and equipment. "Nodal analysis" is the process through which commanders determine which nodes are most critical and vulnerable.

5. MOP 30, p. 3.

6. MOP 6 and MOP 30 both use new terminology for what was formerly electronic surveillance measures, or ESM (now ES), electronic countermeasures, or ECM, (now EA), and electronic counter-countermeasures, or ECCM (now EP). The revised MOP 6 also broadens electronic warfare to include directed-energy weapons.

7. This is a common practice in espionage, where the doubling of agents and the manipulation of unwitting agents are time-honored traditions. The parallel to intelligence craft is no accident, as discussed further below.

8. Initiative and agility are familiar Army terms. The U.S. Army operates on the basis of four key battlefield tenets: initiative, agility, depth, and synchronization. Success in the battle space, according to this philosophy, requires seizing the initiative and retaining it through operations that move faster than the threat, are not limited to frontal confrontation (i.e., that take advantage of the full depth of the battle space), and focus combat power at decisive points. This philosophy is consistent with and complemented by C2W strategy.

9. The "Navy SEW White Paper" (p. 2) refers to "the fourth and fifth dimensions of battle space: the geography of space and the physics of the electromagnetic spectra."

10. "Sanitization" is the process of removing highly sensitive elements (often related to the information's source) in order to render intelligence usable at a lower level of classification.

11. SEW disciplines are divided into two categories, "warfare" and "warfare support." SEW warfare disciplines include operational deception, counter-surveillance, counter-C4I, and electronic combat. The SEW warfare support disciplines are operational security, surveillance, C4I, and signals management. "C4I," in turn, is "command, control, communications, computers, and intelligence."

Ψ

— II —

A Simple, Functional Model of Modern Naval Conflict

Theodore C. Taylor

WORLD WAR II BROUGHT THE FIRST full flowering of air-sea warfare, active defenses, and the extensive use of electronic sensors and countermeasures. These were revolutionary changes in naval warfare, and they generated a concomitant need to revolutionize the modeling and analysis of conflict. That need was soon filled during, and especially after, the war, as the operations research community grasped the possibilities for their profession of the newly available digital computers. Before long, computer-based conflict models had become the accepted touchstones of prowess in conflict analysis. The extent of present-day reliance on computer-based models, as well as insights into some of the problems they brought with them, are presented well in a book on military modeling published a decade ago.[1]

The evolution of military modeling as a widely practiced profession has, as could be expected, left the non-specialist military thinker, civilian, or serving officer "out of the loop." Whereas such thinkers might have the numerical literacy to understand Bradley A. Fiske's attrition tables or even the facility with simple differential equations needed to read F.W. Lanchester's original work, they would almost certainly have to take the products of modern operational research work on faith alone, if at all.[2]

The purpose of this essay is to rescue the non-specialist in operations research from this dilemma. Its aim is to provide a cognitive tool, accessible to those who

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sense the need for a credible means of quantitatively understanding modern conflict but are not conversant with the arcane ruminations of the specialist. That tool may serve those who want to do their own "back of the envelope" calculations, if only as a "sanity check" on obscurely based results. The reader need have only a reasonable notion of what is meant by probability of success (or alternatively, military effectiveness) for a specified event and be able to read with comprehension simple arithmetical statements expressed in elementary algebra.

In what follows, we will do what should be done for any analytical model to test its credibility, namely:

- Provide a complete construction of the model, including definitions of all terms to be used (i.e., the *vocabulary* of expression) and derivations of all expressions to be used (the *statements* to be made);
- Apply the model to an historical example sufficiently broad to make use of all of the model's principal expressions and thus *empirically verify* its usefulness; and,
- Reconcile the model to self-evident or rigorously proven truths and relationships in order to project the model's validity beyond selected empirical examples.

Construction of the Model

Modern naval conflict can be thought of as comprising in essence three fundamental processes, or functions, potentially to be performed by each of the adversaries in a tactical action. Those functions are:

- target detection and identification;
- attacking the targets; and,
- active defense against attack.

Not all of these functions are always performed by both parties. An example from the Falklands conflict is apt. A salvo of two Exocet missiles was launched by Argentine Super Etendard aircraft against the destroyer HMS *Sheffield*; one of the missiles found its target, and, although its warhead failed to explode, its fuel ignited combustibles, and the ship could not be saved. The Argentine force had performed the first two functions of the list above, and the British ship none. Nonetheless, in a full-blown tactical action each party might perform all three functions, so in a complete functional model of modern conflict they must all be represented, and for each participant.

We will now construct a model using probabilities of success for each of the three fundamental functions as its primary terms, or vocabulary. S_B and S_R will respectively denote the probabilities of success for the BLUE and RED forces in the "scouting," or target detection and identification, process. A_B and A_R will denote the probabilities of each offensive attack destroying its targets, *in the absence of any active defense*. That is, in the example of BLUE attacking a single RED ship, A_B is the likelihood that the BLUE salvo will put the *undefended* RED ship totally out of action, at least for the duration of the fight (that is, a "mission kill"). A_B is thus a measure of the lethality of the BLUE salvo against RED when only RED's *passive* defense characteristics are relevant. Finally, D_B and D_R will respectively denote the probabilities of a successful active defense by each force, whether by "hard" or "soft" kills.* For the terms as now defined, the interactions between BLUE and RED forces in tactical action are expressible in the following two equations, where K_B and K_R denote the respective probabilities of the BLUE and RED forces being destroyed:

$$K_B = S_R A_R(1 - D_B) \qquad \text{(Equation 1)}$$

$$K_R = S_B A_B(1 - D_R) \qquad \text{(Equation 2)}$$

Since all the symbols used represent probabilities of success, they must represent numerical values lying in the range from zero to one. When they hold the lower-bound value of zero, they represent no likelihood whatever of success; the upper-bound value of one represents certainty of success. For any probability of success, such as D_B, its *ones-complement*, $(1 - D_B)$, represents the corresponding probability of failure. This follows because the process represented—active defense, in this example—must either succeed or fail, and so the sum of the probabilities D_B and $(1 - D_B)$ must equal one, and of course it does. Given all of that, equation (1) can be expressed in words as follows: the probability of RED's success in destroying BLUE equals RED's probability of success at detecting and identifying its targets, multiplied by RED's probability of successful attack (in the absence of active defense by BLUE), and multiplied by BLUE's probability of failure at active defense. Clearly, equation (1) is a far more economical way of making the statement.

The two equations can be simplified a little by substituting the terms V_B for $(1 - D_B)$ and V_R for $(1 - D_R)$, where these new terms denote the probabilities that each side is *vulnerable* due to failure of its active defense. The equations then become,

$$K_B = S_R A_R V_B \qquad (3)$$

$$K_R = S_B A_B V_R \qquad (4)$$

These expressions are of the simple, multiplied-term form because we are dealing with *conditional* probabilities. So, in equation (4), V_R is the probability that RED's active defense is vulnerable, where BLUE attacks with effectiveness A_B, and BLUE has detected and identified the target with a probability S_B. For illustration, assume that BLUE has a 0.5 probability of finding a RED ship as a target and also

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* A "hard" defensive kill involves the physical destruction of the attacker or the weapon—for instance, an incoming cruise missile. A "soft" kill simply denies the attacker a hit—for instance, by electronically deceiving that missile.

a 0.5 probability of effectively attacking that target once it is detected (not considering the target's active defense). Assume further that the Red's active defense has a 0.5 probability of defeating an effective attack (or, equivalently, a 0.5 probability of being vulnerable to such an attack). Then the overall likelihood of Blue killing this Red ship is $(0.5) \cdot (0.5) \cdot (0.5)$, or 0.125.*

Obviously, estimating conditional probabilities precise enough to draw fine distinctions from equations such as (3) and (4) is a matter for experts. For the rational analysis of modern conflict, however, we will not need precise values, as will later be shown by example. Before proceeding to that, however, a little more work will expand the scope and usefulness of the model much beyond that of equations (3) and (4) alone. Those two equations depict only the probabilities of success for each force—K_B, for example, being the probability of Red's success at "killing" targets in the Blue force. But failures are often better teachers than successes, and so it is worthwhile to expand the model to account for them.

The best way to explore all possibilities within the scope of our three-function model is with the aid of a taxonomic diagram, figure 1. This diagram identifies all categories of outcomes possible when Blue wishes to take action against Red; a similar diagram could be constructed for Red against Blue. Reading horizontally across the top, we consider the two probabilities involved in the scouting process. $(1 - S_B)$ is the probability that Blue acquires no targets, of which the bottom-line result is Case I, in which nothing of a tactical nature happens. S_B is the probability that Blue does acquire targets, and in the next horizontal line below it is multiplied by each of the attack-phase probabilities. Completing the top horizontal line, we note that $(1 - S_B)$ plus S_B equals a total probability of 1, as it should.

The first term of the second line is $S_B(1 - A_B)$, the probability that targets are detected and identified *and* that the Blue attack is ineffective (e.g., all misfires, misses, or duds, without regard to Red's defense). This term leads to Case II, which represents a tactical attempt without result. The second term on this line is $S_B(A_B)$, the probability of successful scouting *and* a potentially lethal attack (i.e., Red's defense not yet considered) by Blue. The sum of the two terms on this horizontal line equals S_B, as it should. This second term, $S_B(A_B)$, must now be multiplied by each of the active-defense-phase probabilities (here represented in terms of vulnerabilities) on the line below. Those products yield the Case III and Case IV bottom-line results, which are $S_BA_B(1 - V_R)$—the probability that the Blue attack is foiled by Red's active defense—and $S_BA_BV_R$, the probability that the Blue attack succeeds. The sum of the two terms on this third horizontal line of the

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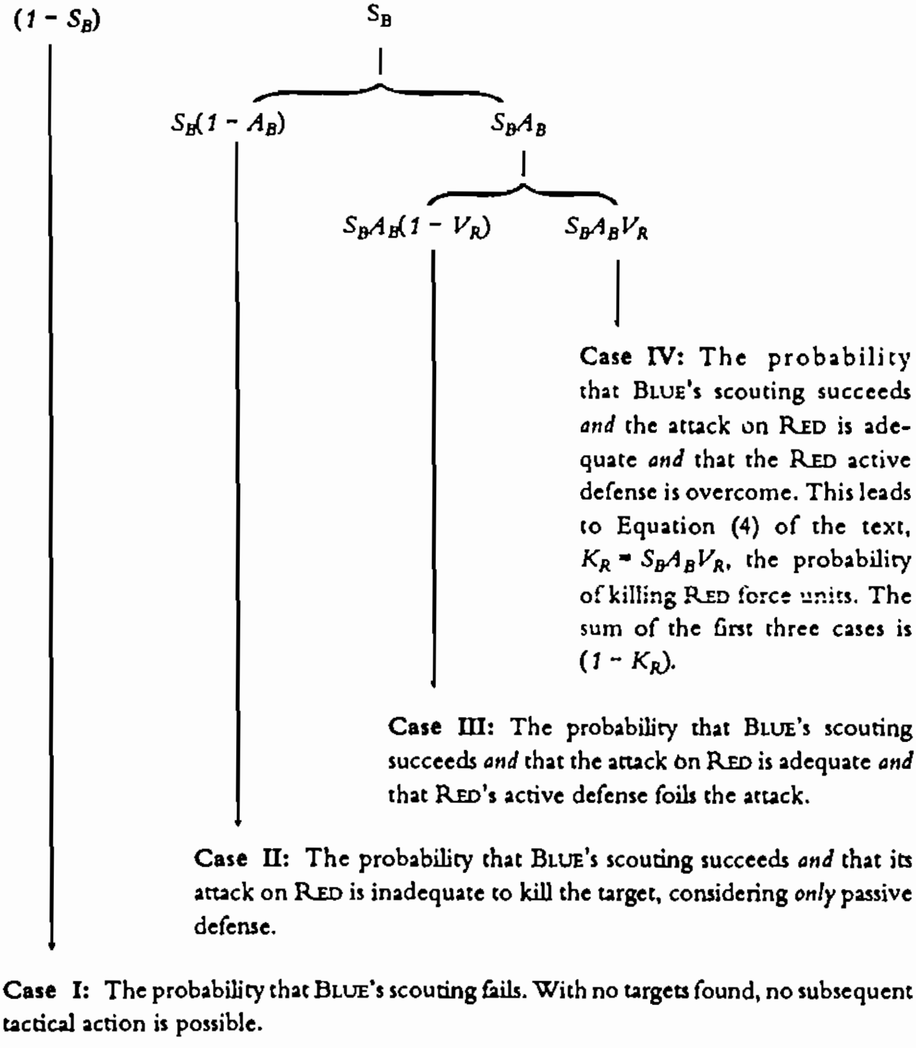
* The raised dot means "multiplied by." We use it here to avoid possible confusion of the usual multiplication symbol with the familiar variable x.

Figure 1
A Taxonomic Outcome Probability Diagram



Case IV: The probability that BLUE's scouting succeeds *and* the attack on RED is adequate *and* that the RED active defense is overcome. This leads to Equation (4) of the text, $K_R = S_BA_BV_R$, the probability of killing RED force units. The sum of the first three cases is $(1 - K_R)$.

Case III: The probability that BLUE's scouting succeeds *and* that the attack on RED is adequate *and* that RED's active defense foils the attack.

Case II: The probability that BLUE's scouting succeeds *and* that its attack on RED is inadequate to kill the target, considering *only* passive defense.

Case I: The probability that BLUE's scouting fails. With no targets found, no subsequent tactical action is possible.

taxonomic diagram is, properly, S_BA_B. Further, the final expressions, from $(1 - S_B)$ to $S_BA_BV_R$, add up to a probability of one:

$$(1 - S_B) + S_B(1 - A_B) + S_BA_B(1 - V_R) + S_BA_BV_R = 1. \tag{5}$$

That they do proves that we have considered all of the probabilities that can occur, that is, the universe of possibilities that exists for the combinations of scouting and attack by BLUE, confronted by active defense by RED. As will shortly be shown by a well known example, all the bottom-line results of figure 1 can and do occur in the real world of naval tactics.

At this point, the model can be extracted from the realm of operations analysts and probability mathematicians and made more useful to practitioners interested in thinking rationally, systematically, and constructively about modern naval warfare. We may now propose and use some practical approximations.

On a *per target* basis, figure 1 can be readily interpreted and understood for the conditions of modern naval warfare, certainly with respect to the cases that establish the bounds of possibilities. First, considering a Blue attempt against Red, an individual target is either detected and identified or it is not, and so we need only consider the cases of $S_B = 1$ and $S_B = 0$. Second, modern offensive weapons (e.g., missiles, guided bombs) are very lethal in relation to the fragility and volatility of their targets (e.g., ships or aircraft with little passive protection carrying stores of fuels and ordnance). With few (but significant) exceptions, salvos of these weapons, if of appropriate size, are more than a match for their targets.[3] Hence, we may consider only the cases of $A_B = 1$ for a properly delivered and routinely fortunate attack and $A_B = 0$ for all others. Finally, given the above, which implies near-total reliance on active countermeasures, that defense is either essentially perfect, for which $V_R = 0$, or else virtually useless, for which $V_R = 1$.

Using these "all or nothing" simplifying assumptions, the four possible outcomes of figure 1 can be derived as summarized in figure 2. These simplified outcomes are no longer fractional probabilities as in figure 1 but all-or-nothing cases—"no kill," i.e., $K_R = 0$, or "kill," $K_R = 1$—applicable to an *individual target* in the Red force. A similar set of outcomes is easily derived from a Red attempt against Blue.

An Empirical Example

Armed with this simplified version of the more general model, we will now examine the battle of Midway.[4] We will actually consider only one aspect of the battle, treating it as an action in which each side sought to destroy the aircraft carriers of the other side by repeated attacks or attempted attacks, ignoring ancillary events such as the Japanese strike on Midway itself. The analysis is on a per-target (carrier) basis; U.S. forces are denoted as Blue, the Japanese as Red. Each attack wave, or "pulse," is summarized by the expression for the attacker's success probability (which is of course known), given as an illustration of how to employ this probability model.

In addition to the all-or-nothing probability values of 0 or 1 for the three basic tactical processes, we add the additional symbol U, for either "unknown" or "unneeded." U is used whenever an earlier probability of the sequence S_B, A_B, V_R is zero, making the others irrelevant since the product is zero in any case. Thus, if Blue succeeds at scouting but attacks ineffectively, the result can be summarized as a simplified Case II (figure 2), by the statement

Figure 2

Simplified Outcomes

(Single-target, simplified-assumption outcomes for the general cases of figure 1)

Case I

$S_B = 0$ (scouting fails), so the known outcome from figure 1 is $(1 - S_B) = 1$, or certainty, and no other outcomes are possible. The three-process description for simplified Case I is therefore:

$$S_B A_B V_R = 0 \cdot A_B V_R = 0 \text{ (no kill).}$$

Case II

$S_B = 1$ (scouting succeeds) *and* $A_B = 0$ (attack is inadequate), so the known outcome is $S_B(1 - A_B) = 1$, and no other outcomes are possible. The three-process description for simplified Case II is therefore:

$$S_B A_B V_R = 1 \cdot 0 \cdot V_R = 0 \text{ (no kill).}$$

Case III

$S_B = 1$ (scouting succeeds) *and* $A_B = 1$ (the attack is adequate), *but* $V_R = 0$ (Red's active defense is invulnerable), so the known outcome is $S_B A_B(1 - V_R) = 1$, with no other outcomes possible. The three-process description for simplified Case III is:

$$S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0 \text{ (no kill).}$$

Case IV

$S_B = 1$ (scouting succeeds) *and* $A_B = 1$ (the attack is adequate), *and* $V_R = 1$ (Red's active defense fails), so the only possible outcome for simplified Case IV is:

$$S_B A_B V_R = 1 \cdot 1 \cdot 1 = 1 \text{ (a kill).}$$

$K_R = S_B A_B V_R = 1 \cdot 0 \cdot U = 0$. First modelled are Japanese attacks on U.S. carriers.

- First attack on USS *Yorktown* by *Hiryu*-based dive bombers:

$$K_B = S_R A_R V_B = 1 \cdot 1 \cdot 1 = 1$$

(The *Yorktown* was disabled; but progress in quenching fires and patching the flight deck was rapid, and speed was restored to nineteen knots. Nevertheless, she had ordered her returning aircraft to land on *Hornet* or *Enterprise* and did not resume flight operations during the battle, so this attack must be credited to RED as a "mission kill.")

- Second attack on *Yorktown* by *Hiryu*-based torpedo planes:

$$K_B = S_R A_R V_B = 0 \cdot U \cdot U = 0$$

(An interesting situation: the Japanese had correctly assessed that the *Yorktown* was out of the fight and reattacked only in the mistaken impression [produced by the remarkably fast repairs] that they had found some different carrier. Hence, with regard to the attack *intended*, $S_R = 0$, and the "added value" to their score of carriers killed is 0.)

Now follow a number of U.S. attacks on Japanese carriers.

- On *Hiryu*, by Midway-based torpedo planes:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(Active defense—by Zero fighters, evasive maneuvers, and machine-gunning of torpedoes—was perfect.)

- On *Akagi*, by Midway-based torpedo planes:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(Active defense by Zero fighters and evasive maneuvers was perfect.)

- On *Hiryu*, by Midway-based glide-bombing planes:

$$K_R = S_B A_B V_R = 1 \cdot 0 \cdot U = 0$$

(Five of the planes survived the Japanese active defense and released bombs, with no hits. The attack technique was ineffective, and $A_B = 0$.)

- On *Kaga*, by Midway-based glide-bombing planes:

$$K_R = S_B A_B V_R = 1 \cdot 0 \cdot U = 0$$

(Three planes survived to release bombs, with the same conclusion as in the attack above.)

- On *Soryu*, by Midway-based B-17s in high-level bombing attack:

$$K_R = S_B A_B V_R = 1 \cdot 0 \cdot U = 0$$

(Gravity-bombing the moving ship from 20,000 feet was totally ineffective; $A_B = 0$.)

- On *Hiryu*, by Midway-based B-17s in high level bombing attack:

$$K_R = S_B A_B V_R = 1 \cdot 0 \cdot U = 0$$

(Same as the attack on *Soryu*, above.)

- Attempted attack by Midway-based, glide-bombing aircraft on a carrier, delivered instead against battleship *Haruna*:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(With respect to the hoped-for attack on a carrier, the intensity of the active defense over the whole formation must be credited as $V_R = 0$. If we were considering battleships as targets, the score would be the same, a combination of fighter defense and *Haruna*'s evasive maneuvers. Here we grant that a glide-bombing attack might have been effective [$A_B = 1$], despite the two earlier examples.)

- Attack on *Soryu* by *Hornet*-based torpedo planes:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(All fifteen planes of the attacking force were shot down by Zeros.)

- On *Kaga*, by *Enterprise*-based torpedo planes:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(Active defense by Zeros and *Kaga*'s evasive maneuvers.)

- Sortie by *Hornet*-based dive bombers:

$$K_R = S_B A_B V_R = 0 \cdot U \cdot U = 0$$

(These thirty-five planes found no targets.)

- Attack on *Hiryu* by *Yorktown*-based torpedo planes:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 0 = 0$$

(Defense by Zeros plus evasive maneuvers by *Hiryu*.)

- On *Kaga*, by *Enterprise*-based dive bombers:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 1 = 1$$

(With active defense unready, at least four hits were made, with secondary explosions of fuel and ordnance stores.)

- On *Akagi*, by *Enterprise*-based dive bombers:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 1 = 1$$

(At least three hits, plus secondary explosions.)

- On *Soryu*, by *Yorktown*-based dive bombers:

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 1 = 1$$

(Again, at least three hits, plus secondary explosions.)

- Finally, an attack on *Hiryu* by *Enterprise*-launched dive bombers (some from the now-disabled *Yorktown*):

$$K_R = S_B A_B V_R = 1 \cdot 1 \cdot 1 = 1$$

(Probably four hits.)

A disturbing lesson arises from the U.S. performance in these engagements, as summarized in tables 1 and 2. The mere 6.67 percent of Case I outcomes testifies to the quality of U.S. pre-battle intelligence and the scouting based upon it. However, the Case IV outcomes add up only to what amounts to a random draw, and they reflect no credit whatever on U.S. preparation and training for battle, whereas the Case III percentage testifies to the excellence of Japanese active defense. In passing, we may note that the simplified probability model was able to handle all of the fifteen attempted attacks by U.S. forces. The table 2 percentages, expressed as decimal fractions and used with the case-outcome expressions of figure 1, can be used to calculate the three fundamental process probabilities of success, in an after-the-fact sense, for the battle of Midway as modeled here. The answers are, $S_B = 0.933$, $A_B = 0.714$, and $V_R = 0.400$; and $S_B A_B V_R$ is therefore 0.266,* agreeing

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* The slight discrepancy is due to calculation with only three significant figures.

Table 1
Per-Target Actions
Attempted by U.S. Forces (Simplified Cases)

Against *Kaga*	Against *Akagi*	Against *Hiryu*	Against *Soryu*	Against Indeterminate
II	III	III	II	I
III	IV	II	III	III
IV		II	IV	
		III		
		IV		

Table 2
Attempted U.S. Attacks

Simplifed Cases	Total Number	Percentages
I	1	6.67
II	4	26.67
III	6	40.00
IV	4	26.67

Note: A random drawing for each species of outcome would yield 25 percent each.

with the table 2 value for the fraction of all U.S. sorties that were successful at Midway. Thus, summarizing *per-target* results gives consistent *battle* results, as it should, and permits the estimation of probabilities of success for the two U.S. offensive functions and the Japanese active defense vulnerability (or, alternatively, the Japanese active-defense success probability, 0.600).

The reader should understand that these numbers are an *example* set—the product of the set of assumptions used together with facts from which they were obtained. It is *fact* that four Japanese carriers were destroyed, that fifteen sorties were flown against them of which fourteen resulted in actual attempted attacks, and that the four kills were achieved by dive bombers. But it was *assumed* that five torpedo-bomber and one glide-bomber attack would have been equally effective had they not been foiled by the Japanese defense. That assumption seems reasonable (at least for torpedo attacks) in light of World War II actions other than Midway. Therefore, the numbers $A_B = 0.714$ and $V_R = 0.400$ are derived from a mixture of facts and assumptions, with only $S_B = 0.933$ being indisputably factual. So what we have here is not "irrefutable truth" even for Midway, where we know the bottom line. Rather, it is an example of how to use a rigorous, conceptual framework to organize analysis wherein many numbers affect the result, and many numbers may be debatable.

Reconciliations to Other Theory

Having shown the model's potential usefulness with the empirical example of the battle of Midway, we may now buttress its credibility in a more general sense. First, we can show that the model is not inconsistent with Frederick William Lanchester's well known "n-square law." The ratio of equation (4) to equation (3) is:

$$\frac{K_R}{K_B} = \frac{S_B A_B V_R}{S_R A_R V_B}. \qquad (6)$$

Lanchester's original work defined forces as having equal "fighting strengths" when each was capable of reducing the opposing force in the same proportion per unit of time. For example, if a force of five ships fights ten ships, and the larger force loses two ships per hour while the smaller loses one per hour, they are said to be equal in fighting strength. In the terminology of the present model, equivalence in fighting strength exists if each force has the same probability of destroying the other in any specified time interval—such as during an entire engagement. Thus, K_R and K_B must be equal, so that their ratio, as in equation (6), would be one.

Also, Lanchester's work did not address the subject of scouting but merely assumed that the forces in conflict would detect and identify all targets—i.e., in the present model, the situation of $S_B = 1$ and $S_R = 1$. Similarly, Lanchester did not contemplate active defense but analyzed only the attrition between forces taking offensive actions; the analogous situation for the present model is $V_B = 1$ and $V_R = 1$. Thus, in the Lanchester approach equation (6) degenerates to:

$$\frac{A_B}{A_R} = 1. \qquad (7)$$

Now let n_B and n_R denote respectively the numbers of fighting units in the Blue and Red forces, and f_{KR} denote the probability of a single Blue unit killing a Red unit during a specified time interval. Then the *expected* number of Red units killed is $n_B f_{KR}$, and the *fraction* of the whole RED force killed is given by $n_B f_{KR}/n_R$. However, under the assumption that the probability of success in killing the whole RED force applies as well to each of its individual units, the expected value for RED units killed is $n_R A_B$, and the *fraction* of the total force killed is $n_R A_B/n_R = A_B$. But we have just derived another expression for this fraction, and so we can write:

$$A_B = \frac{n_B f_{KR}}{n_R} \tag{8}$$

and, by analogy,

$$A_R = \frac{n_R f_{KB}}{n_B}. \tag{9}$$

By substituting (8) and (9) into (7) and rearranging, it may be found that

$$f_{KB} n_R^2 = f_{KR} n_B^2. \tag{10}$$

Except for different notation, this equation is precisely Lanchester's n-square law.[5] Thus, not only is the present model consistent with the Lanchester law, but the latter is derived from a special, reduced case of the former, expressed as equation (7).

One more special case is of interest, to validate the model further. Consider the situation where RED completely surprises BLUE; that is, BLUE is able neither to defend actively nor return offensive fire. The corresponding applications of equation (3) and (4) are:

$$K_B = S_R A_R V_B = S_R \cdot A_R \cdot 1 = S_R A_R \tag{11}$$

and,

$$K_R = S_B A_B V_R = S_B \cdot 0 \cdot U = 0, \tag{12}$$

where we have contemplated that BLUE might have actually detected and identified its potential targets, but not in time to do anything about it. RED survives intact, since $K_R = 0$, whereas BLUE suffers the full effect of RED's assault. In the very simple example cited earlier of HMS *Sheffield* (taken as BLUE), the version of equation (11) was:

$$K_B = S_R A_R V_B = 1 \cdot 1 \cdot 1 = 1. \tag{13}$$

It is important that a model be able to depict surprise in conflict, since surprise is the best means available to a tactical commander for degrading the enemy's capabilities.

Finally, a model worthy of general use should be self-evidently true to anyone conversant with its idiom. The present model has that property, as is evident from a rearrangement of equation (6):

$$\frac{K_R}{K_B} = \left[\frac{S_B A_B}{V_B}\right] / \left[\frac{S_R A_R}{V_R}\right] \qquad (14)$$

Expanded into words, this equation says that Blue can maximize his ratio of kills of Red to his own losses by maximizing the effectiveness of scouting and attacking, and by minimizing his own vulnerability—no more than a truism, as it should be. Its essence was captured in similar words by Mao Tse-tung:

> *The first law of war is to preserve ourselves and destroy the enemy.*[6]

A model that gives quantitative meaning to such simple words can be a powerful cognitive asset to the analysis and understanding of modern naval conflict.

Notes

1. Wayne P. Hughes, Jr., ed., *Military Modeling* (Alexandria, Va.: Military Operations Research Society, Inc., 1984). The introduction provides a good summary.

2. Bradley A. Fiske, *The Navy as a Fighting Machine* (New York: Charles Scribner, 1916), p. 284. Fiske published a number of attrition tables, over a number of years; this reference is representative. For Lanchester, J.R. Newman, *The World of Mathematics* (New York: Simon and Schuster, 1956), pp. 2138–57. This republication of Lanchester's original work is available in most modern technical libraries.

3. The exceptions are certain vessels of such size and internal arrangement that they may well remain operational even after repeated hits. Modern aircraft carriers are so elaborately equipped against conflagration that, their obvious vulnerabilities notwithstanding, disablement is at least not to be assumed. Also, as both Iranian and Iraqi pilots learned in the "tanker war," however many Exocets one launches, it can be surprisingly difficult even to set fire to bulk oil carriers—seemingly the most helpless and combustible of targets. Notwithstanding, there are antiship weapons (notably the SS-N-19 cruise missile) powerful enough at least to put out of action all but the largest and best protected target, and the vast majority of warships are not in that category. One Exocet destroyed the *Sheffield*, two of them wrecked the frigate USS *Stark* (FFG 31), and Japanese bombs and torpedoes wreaked havoc at Pearl Harbor among even heavily armored ships not putting up an effective active defense.

4. The following discussion is based upon Walter Lord, *Incredible Victory* (New York: Simon and Schuster, 1968). Two other classics on the subject also proved helpful: Mitsuo Fuchida and Masatake Okumiya, *Midway, the Battle that Doomed Japan* (Annapolis, Md.: U.S. Naval Institute Press, 1955), and Gordon W. Prange, *Miracle at Midway* (New York: Penguin, 1983).

5. As Lanchester expressed it, his *n*-square law is:

$$Nr^2 = Mb^2,$$

where r and b denote respectively the numbers of Red and Blue fighting units, and N and M the "fighting values" of individual units.

6. Robert Debs Heinl, Jr., *Dictionary of Military and Naval Quotations* (Annapolis, Md.: Naval Institute Press, 1966), p. 169.

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