Chapter One

INTRODUCTION

Traditional measures of effectiveness (MOEs) usually ignore the effects of information and decisionmaking on combat outcomes. In the past, command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) operations have been analyzed separately using measures of performance (MOPs). Assessing the effects of improvements in C4ISR operations on combat outcomes has been inferred rather than directly assessed. For example, such physical improvements as greater bandwidth are generally thought to be beneficial to combat operations. The same is true for improved sensors and fusion algorithms and their salutary effects on the common operating picture (COP). Even the more recent discussions of network-centric warfare (NCW) or network-centric operations (NCO) (Cebrowski, 1998) and information superiority imply that their effects will be to improve combat operations by improving decisionmaking. However, the quantifiable link between these improvements in C4ISR and combat outcomes has been relatively difficult to assess. The problem has been widely recognized: for example, Alberts et al. (2001) state in their recent book:

For many, Information Superiority and Network Centric Warfare remain abstract concepts, their applicability to military operations and organizations [are] unclear, and their value unproven. Others have seen the benefits but are unable to “connect the dots” between improved information . . . and outcomes in a [scientifically] rigorous . . . way.
NCW

NCW is generally thought to be the linking of platforms into one, shared awareness network in order to obtain information superiority, get inside the opponent’s decision cycle, and end conflict quickly. In contrast to network-centric operations or warfare, traditional warfare is considered to be platform-centric. The difference between the two is that in platform-centric warfare, one must mass force to mass combat effectiveness because each weapon system acts independently, whereas in NCW effects are massed, rather than force. That is, the employment of weapon systems is optimized so that a target is serviced by the most effective system in the network.\(^1\) Thus, it is hypothesized, the effects of massing force can be obtained with a much smaller force. The Navy and the C4ISR community are pursuing the application of this concept to warfare.

NCW is based on the concept of three network grids:

- **The information network grid:** The information grid provides the infrastructure to “receive, process, transport, store, and protect information for the Joint and combined services” (Stein, undated).

- **The sensor network grid:** The sensor grid is a need-based network that uses the sensors in the information grid pertinent to a given task. It is made up not only of such typical warfare sensors as radar but also of imbedded logistics sensors to track supply. The sensor grid is unique to each task.

- **The engagement-decision-shooter grid:** Sensor and warfighter elements of the network are tasked to attack in the engagement grid. This grid, like the sensor grid, is dynamic, using a unique blend of warfighters and sensors for each new task (Stein, undated).

The latter two grids are completely contained in the information network grid. Each grid is composed of nodes represented by individual sensors, weapons, or command platforms and is connected via networked data and communication. The sensor and engage-

\(^{1}\)Actually, the word “optimized” is a bit strong. “Improved considerably” is closer to the truth.
ment grids are not necessarily separate. They often have overlapping components. For example, the sensor grid begins a track on a cruise missile and continues to track as the pertinent unit engages and a kill is made.

NCW flattens the command and control pyramid. Commanders communicate intent through the introduction of doctrine in the form of computer algorithms as well as communicating directly with individual units. NCW moves toward automated optimization of the positions of units in a group and engagement of enemy forces using new initiatives such as the Navy’s Cooperative Engagement Capability\(^2\) (CEC) and Ring of Fire.\(^3\)

**OBJECTIVES**

The primary objective of this project is to create a framework for developing measures and metrics that adequately assess the impact of changed C4ISR systems and procedures on combat outcomes. In the process, sample measures and metrics are suggested that achieve this goal. These are presented with the idea of generating dialogue in the naval and C4ISR communities concerning the framework and the measures and metrics suggested. This is clearly overdue.

Although measures are simply *bases* or *standards* of comparison, and can therefore be described qualitatively, metrics must be mathematical expressions that allow us to evaluate, not only the relative effect of alternative C4ISR systems on combat outcomes, but also the degree to which one is better or worse than another. This argues for rigorous mathematical formulations that produce accurate results. It is important to note, however, that the process reported in this document is deductive—i.e., none of the equations presented in the text

\(^2\)CEC is designed is to combine the raw sensor data from all platforms involved in an operation, regardless of age or type of sensors on individual platforms. It allows the combined data from these sources to produce a more complete, shared COP for tracking purposes. For additional information see “The Cooperative Engagement Capability,” *Johns Hopkins APL Technical Digest*, 16/4, 1995.

\(^3\)The Ring of Fire (ROF) concept is a network-centric approach to littoral warfare. It links land, sea, and air forces to produce calls for fire. Like the CEC, ROF networks sensor and weapon information for sea, shore, and command forces in the littoral to produce an extended and more accurate COP. See Mitchell, R., “Naval Fire Support: Ring of Fire,” *US Naval Institute Proceedings*, 123/11:54, November 1997.
is based on experimental or operational data. Validation and calibration remain tasks for future work.

Naval warfare covers a wide range of disparate operations and, therefore, demands a variety of measures and metrics to assess the outcomes analytically. Consequently, it is important that an analysis of this kind encompass a variety of engagements to ensure the adequacy of the framework and the metrics developed. The objective then is to select a single major conflict and examine several vignettes within the scenario. The scenario selected was a notional future (2010) conflict involving the defense of threatened allied territory. Two vignettes were selected for examination:

- **Cruise and ballistic missile attack**: The first is a coordinated anti-ship cruise missile (ASCM) saturation strike against U.S. surface combatants and a ballistic missile attack against targets being defended by those surface combatants. An ASCM attack might prevent those ships from protecting against ballistic missiles by disabling a ship or saturating its command and control systems so that ballistic missiles can “leak” through.

- **Time-Critical Targets (TCTs)**: The classic TCT vignette for analysis is operation against a Transportable-Erector-Launcher (TEL), such as an enemy Scud launcher. However, the vignette selected for analysis in this work is the search for and destruction of an enemy submarine leaving port en route to interdict friendly ports. The submarine must be destroyed before it submerges.

Finally, the framework and the measure and metrics developed are demonstrated using a spreadsheet model. The objective is to provide the analyst with a proof-of-concept tool that will quickly generate several alternatives based on varying operating procedures, network connectivity, and C4ISR systems. The relative value of the alternatives is assessed in terms of the contribution each makes to combat outcomes. The contribution may be defined differently for each vignette evaluated. Several hundred alternatives can be easily generated using the spreadsheet models, and therefore the use of exploratory analysis as an evaluation tool is required. “Exploratory analysis” refers to the use of many computational experiments to
reason about complex and uncertain problems. Recently, exploratory approaches have been used for a variety of studies.4

ABOUT THIS REPORT

Chapter Two outlines the basic scenario developed to support this study. Several vignettes were developed from this scenario, and two were singled out for analysis. Chapter Three details the first of these: the defense of allied territory and the engaged fleet against ballistic missile and cruise missile attack. Chapter Four focuses on the second vignette: a TCT analysis problem involving the search for and destruction of a surfaced enemy submarine. Both Chapters Three and Four include the mathematical foundation for the metrics proposed to assess the relationships among NCW, improved command and control processes, and combat outcome. Chapter Five describes the spreadsheet model used to conduct exploratory analysis and Chapter Six concludes with some findings and suggestions for future work. Two glossaries are included to assist the reader with the text. These appear on pp. xxxi–xxxviii. The first describes acronyms and terms used in the text, and the second records the definitions of the several mathematical terms. Finally, an Information Entropy appendix is included.

4For a discussion of exploratory analysis and exploratory modeling, see Bankes (1993) and Davis, Bigelow, and McEver (2001).