# Information Technology for Command and Control

## Methods and Tools for Systems Development and Evaluation

Edited by
Stephen J. Andriole
Stanley M. Halpin

IEEE
PRESS

A volume in the IEEE PRESS Selected Reprint Series, prepared under the sponsorship of the IEEE Systems, Man, and Cybernetics Society.

# INFORMATION TECHNOLOGY FOR COMMAND AND CONTROL

## Methods and Tools for Systems Development and Evaluation

Edited by

**Stephen J. Andriole**
Drexel University

**Stanley M. Halpin**
Army Research Institute



**IEEE PRESS**



A volume in the IEEE PRESS Selected Reprint Series,
prepared under the sponsorship of the
IEEE Systems, Man, and Cybernetics Society.

The Institute of Electrical and Electronics Engineers, Inc., New York

IEEE PRESS
445 Hoes Lane, PO Box 1331
Piscataway, NJ 08855-1331





**ISBN 0-87942-270-X**

**IEEE Order Number: PC0264-2**

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

**Library of Congress Cataloging-in-Publication Data**

Information technology for command and control : methods and tools for systems development and evaluation / edited by Stephen J. Andriole, Stanley M. Halpin.
p. cm. -- (IEEE Press selected reprint series)
"Prepared under the sponsorship of the IEEE Systems, Man, and Cybernetics Society."
Includes bibliographical references and index.
ISBN 0-87942-270-X (casebound) :
1. Command and control systems. 2. Management—Communication systems. 3. Management—Data processing. 4. Decision support systems. I. Andriole, Stephen J. II. Halpin, Stanley M. III. IEEE Systems, Man, and Cybernetics Society.
UB212.I55 1991
355.3'3041'028--dc20 90-20526
CIP

# Preface

THIS volume in the ongoing IEEE Press Selected Reprint Series deals with the multidisciplinary field of command and control ($C^2$). $C^2$ includes the processes by which optimal courses of action are determined and implemented, the process by which assets are allocated in constrained environments, and the processes by which "forces"—be they military, industrial, or governmental—are leveraged against requirements, missions, and threats.

Command and control is complex, almost always characterized by high uncertainty, and more often than not exercised in real time. Those that design, develop, test, and maintain command and control systems must understand their domains, the intended system operators, and the adversarial backdrop to mission performance. Command and control systems engineers must also understand and appreciate the role of advanced technology in the systems design, development, and evaluation process.

This book assumes the importance of information technology for command and control. It assumes that advanced information technology is necessary to cost-effective systems design and development, and that information technology can provide the edge to planners, decision-makers, and commanders.

Most of the papers reprinted here acknowledge the role that information technology can and should play in command and control. The papers illustrate how broad-based information technology can be used to model the command and control process, to determine command and control systems requirements, to build $C^2$ system prototypes, to design and develop decision aids for command and control, and to evaluate the $C^2$ process, $C^2$ systems, and even $C^2$ investment strategies.

It is important to remember that although annual expenditures for military command and control well exceed $25 billion, an enormous amount is spent on command and control in the private sector as well. While many of us conceptually locate command and control on the tactical and strategic battlefield, a growing number of professionals understand command and control as corporate crisis management, air traffic control, law enforcement, and financial management. While many of the papers in this book describe research and applications in military command and control, the generalizability of their technical content to the nonmilitary world is high. This is especially true of intelligent systems technology, user-computer interaction technology, and the principles of information and decision systems engineering.

The book is organized in five parts. Part I presents some insight into the processes by which command and control decision and information system requirements are identified, modeled, and validated. Part II deals with intelligent systems design and development. Part III focuses on advanced user-computer interface technology. Part IV presents some decision support systems case studies, while the final Part (V) of the book deals with how command and control systems ought to be evaluated and how key information technology can be assessed. The papers are followed by a Selected Bibliography (which supplements the references presented in the papers themselves).

It is our hope that this book synthesizes a great deal of disparate material and provides a snapshot of the field of command and control at a particular point in time. We hope that the book can be used by those who design, develop, and evaluate military $C^2$ systems, those who research and develop nonmilitary command and control systems, and those with an interest in the processes by which requirements are converted into operational systems regardless of the substantive domain. In many important respects the design and development of complex, large-scale systems transcends domains. Many in the systems engineering community would argue that the processes by which systems are conceived, designed, developed, evaluated, and maintained are constant, and that while the substantive domains may change, the methods, tools, and techniques of the trade remain the same. One of the essential points of this book is the constant of information technology. Today, it is difficult if not impossible to find a complex, large-scale system without computer software, central processing units, display devices, and the like. Databases proliferate our analytical worlds, and information systems of all kinds depend on information technology for their operation and evolution. It is hoped that this book validates the point and pushes our understanding of information technology to new technical limits via the substantive springboard of command and control.


### Acknowledgments

We would like to acknowledge all of the analysts, scientists, and engineers who design, develop, and evaluate command and control systems. The past decade has yielded deep insight into the command and control process and numerous operational systems. Much of the thinking, analysis, and experimentation that lead to successful systems design and development are documented in this book. We are thus indebted to those who have contributed to the field—and to this book. We would also like to thank Reed Crone and Dudley Kay of IEEE for their editorial help and guidance. Reed Crone initially endorsed the concept for the book, and Dudley Kay, who succeeded Reed Crone as Managing Editor of the IEEE Press, helped bring the book to life. We would also like to thank the IEEE Systems, Man, and Cybernetics Society for sponsoring the book and the U.S. Army Research Institute (ARI) for the Behavioral and Social Sciences for supporting the project.


*Stephen J. Andriole*
*Stanley M. Halpin*

# Contents

## Part V: Evaluation and Assessment Perspectives, Tools, and Techniques 467

# Introduction: Perspectives on Command, Control, and Information Technology

STEPHEN J. ANDRIOLE
DREXEL UNIVERSITY

STANLEY M. HALPIN
ARMY RESEARCH INSTITUTE

## COMMAND AND CONTROL ($C^2$) IN PERSPECTIVE

IF you ask someone in the Pentagon to define "command and control," you will probably hear a lot about the latest communications system just deployed in Europe. Such a response would be interesting from at least two distinct perspectives. On the one hand, command and control is by no means just communications systems—the third "C" in the oft-heard acronym "$C^3$"; in fact, one could argue that communications systems are the means by which command decisions are made and executed and as such are *supportive* of the essential tasks in command and control. On the other hand, the reference to Europe would be interesting, because while command and control of military forces will continue to receive enormous attention worldwide, attention will—if present trends continue—certainly focus away from the now-famous Fulda Gap.

Command and control is the process by which decision-makers (such as executives in industry and commanders in the military) select among competing options to achieve strategic and tactical objectives. On the tactical battlefield, commanders receive input from sensors embedded in larger intelligence systems. The data are processed into analytical forms, and estimates about adversary location and disposition, friendly capabilities, and terrain are generated by large staffs of professionals. The commander then synthesizes the estimates and converts them into a set of options (given his or her objectives or "guidance"). These options become candidate "courses of action." Good commanders use explicit criteria to select among competing options. All of this activity is supported by elaborate communications, computing, and display systems. Without this gear, commanders cannot function, and without command decision-making, there is no command and control.

On corporate battlefields, chief executive officers (CEOs) behave pretty much the same way. Objectives are determined by boards, major stockholders, competition, and market trends. CEOs then assess their (and their adversaries') situations: How strong is our (and their) cash flow position? How deep is our (and their) business backlog? How productive has our (and their) internal research and development (IR & D) program been? The answers to such questions determine overall corporate capabilities. Assets are mobilized to achieve the objectives, but only after a variety of options are identified, defined, and debated. Like his or her military counterpart, the CEO relies heavily upon data collection, analysis, and estimates. He or she also depends on sophisticated communications and computing systems.

Just as the military is preparing to alter its primary mission away from Western Europe, so too must corporate America think about new markets. In many fascinating respects, both "commanders" are now in a period of monumental transition. Because the competition is keener and the stakes are higher, both must continue to rely heavily upon advanced information technology. Predictions have already been made about the rise of the "information society" and the "expert company." In just ten years, military and corporate command and control has changed dramatically; another decade will solidify the place of information technology for command and control.

This book attempts several things. First, it defines command and control from the commander (or executive) out, not from communications systems in. This is a somewhat radical departure from conventional wisdom, which often defines command and control as survivable modems. We view command and control as essentially a human inference and decision-making process. While certainly supported by any number of information, decision, and "expert" systems, it still remains essentially within the purview of the human commander to make decisions. Even in strategic indications and warnings (I & W) systems design and development commanders make design decisions that determine how our strategic forces will behave when confronted with little or no decision time.

Second, the book defines the role of information technology in command and control from the same commander-out perspective. We believe that while information technology of all kinds has been successfully applied to the design, development, and implementation of advanced communications systems, the application of information technology to command inference and decision-making will ultimately yield the most performance leverage. The book thus concentrates on how command and control information and decision support systems can be designed, developed, evaluated, and fielded.

Third, although the book focuses primarily on military command and control, we tried to select papers with high potential for application to other fields. There are also papers with high potential for application to command and control though they were primarily conceived as "generic" or for application in related domains.

We selected papers that deal with the development and application of methods that have been applied to the design and development of command and control information systems, decision support systems, requirements models, and prototypes. Our emphasis is on the methods, approaches, tools, and techniques that can be used to design, develop, evaluate, and field command and control information, planning, and decision support systems.

### Command and Control Information and Decision Systems Analysis and Design

Part I of this book deals with the process by which requirements are converted into operational systems. The paper by the late Joe Wohl, for example, is a superb example of planning, and inference and decision-making requirements analysis. Many of the papers in Part I deal with the question of human information processing and the development of models that would permit information and decision systems architects to support command decision-making. Part I deals with methods and techniques for capturing decision-making expertise, modeling the expertise, and then prototyping systems intended to support and enhance information management, planning, and decision-making. Part I also describes some life cycles for $C^2$ systems design and development.

A variety of tools and techniques is available to the information and decision systems engineer; Part I describes some that have been successfully applied within and beyond the domain of command and control.

Part I also introduces the concept of *distributed* command and control, for which key decision-makers (and assets) are geographically dispersed. This concept has important implications for the design, development, evaluation, and fielding of command and control systems and is discussed in several papers in this book.

Part I focuses on (individual, group, and distributed) information and decision systems requirements analysis, modeling, and prototyping. It describes some efforts to model expertise, develop "storyboard" prototypes, and compare alternative life cycles.

### Intelligent $C^2$ Systems Technology

A variety of tools, methods, techniques, devices, and architectures is available to the $C^2$ systems designer; many more will emerge as we move toward the twenty-first century. The challenge—as always—lies in the extent to which designers can match the right tool or method with the appropriate problem.

Figure 1 suggests the range of methods and models available to the information and decision systems engineer (Hopple, 1986). The taxonomy is by no means complete, although it is representative of the way methods, tools, and techniques can be categorized and assessed. Figure 2 from Andriole (1989) suggests how methods can be rank-ordered against a set of requirements.

Over the past decade the $C^2$ community has seen the preeminence of knowledge-based tools and techniques, although the range of problems to which heuristic solutions apply is much narrower than first assumed. It is now generally recognized that artificial intelligence (AI) can provide knowledge-based support to well-bounded problems in which deductive inference is required (Andriole, 1990). We now know that AI performs less impressively in situations with characteristics (expressed in software as stimuli) that are unpredictable. Unpredictable stimuli prevent designers from identifying sets of responses, and therefore limit the applicability of "if–then" solutions. We now know, for example, that expert systems can solve low-level diagnostic problems, but cannot predict Soviet intentions toward Poland in 1995. While many felt from the outset that such problems were beyond the applied potential of AI, just as many were sanguine about the possibility of complex inductive problem-solving.

The latest methodology to attract attention is neural network-based models of inference-making and problem-solving. As Fig. 3 suggests, neural networks are applicable to problems with characteristics quite different from those best suited to AI. It remains to be seen whether neural networks constitute the problem-solving panacea that many believe they represent. The jury is still out on many aspects of the technology. But like AI, it is likely that neural nets will make a measured contribution to our inventory of models and methods.

In spite of the overselling of AI, the field still holds great promise for the design and development of command and control systems of all kinds. Natural language processing systems—systems that permit free-form English interaction—will enhance decision support efficiency and contribute to the wide distribution of information and decision systems.

Expert systems will also make many decision-making processes routine. Rules about investment, management, resource allocation, and office administration will be embedded in expert information and decision systems. Problems that now have to be re-solved whenever a slight variation appears will be autonomously solved. Smart database managers will develop necessary databases long before decision support problems are identified. $C^2$ systems of the 1990s will be capable of adapting from their interactions with specific users. They will be able to anticipate problem-solving "style" and the problem-solving process most preferred by the user. They will be adaptive in real time, and capable of responding to changes in the environment, like a shortage of time.

The kinds of problems that will benefit the most from AI will be well bounded, deductive inference problems about which a great deal of accessible and articulate problem-solving expertise exists.

Information and decision systems engineers in the 1990s will also benefit from a growing understanding of how humans make inferences and decisions. The cognitive sciences are amassing evidence and perception, biasing, option generation, and a variety of additional phenomena directly related to decision support systems (DSSs) modeling and problem-solving. The world of technology will be informed by new findings; resultant systems will be "cognitively compatible" with their users.

Hybrid models and methods drawn from many disciplines and fields will emerge as preferable to single model-based solutions largely because developers will finally accept diverse requirements specifications. Methods and tools drawn from the social, behavioral, mathematical, managerial, engineering, and computer sciences will be combined into solutions driven by requirements and not by methodological

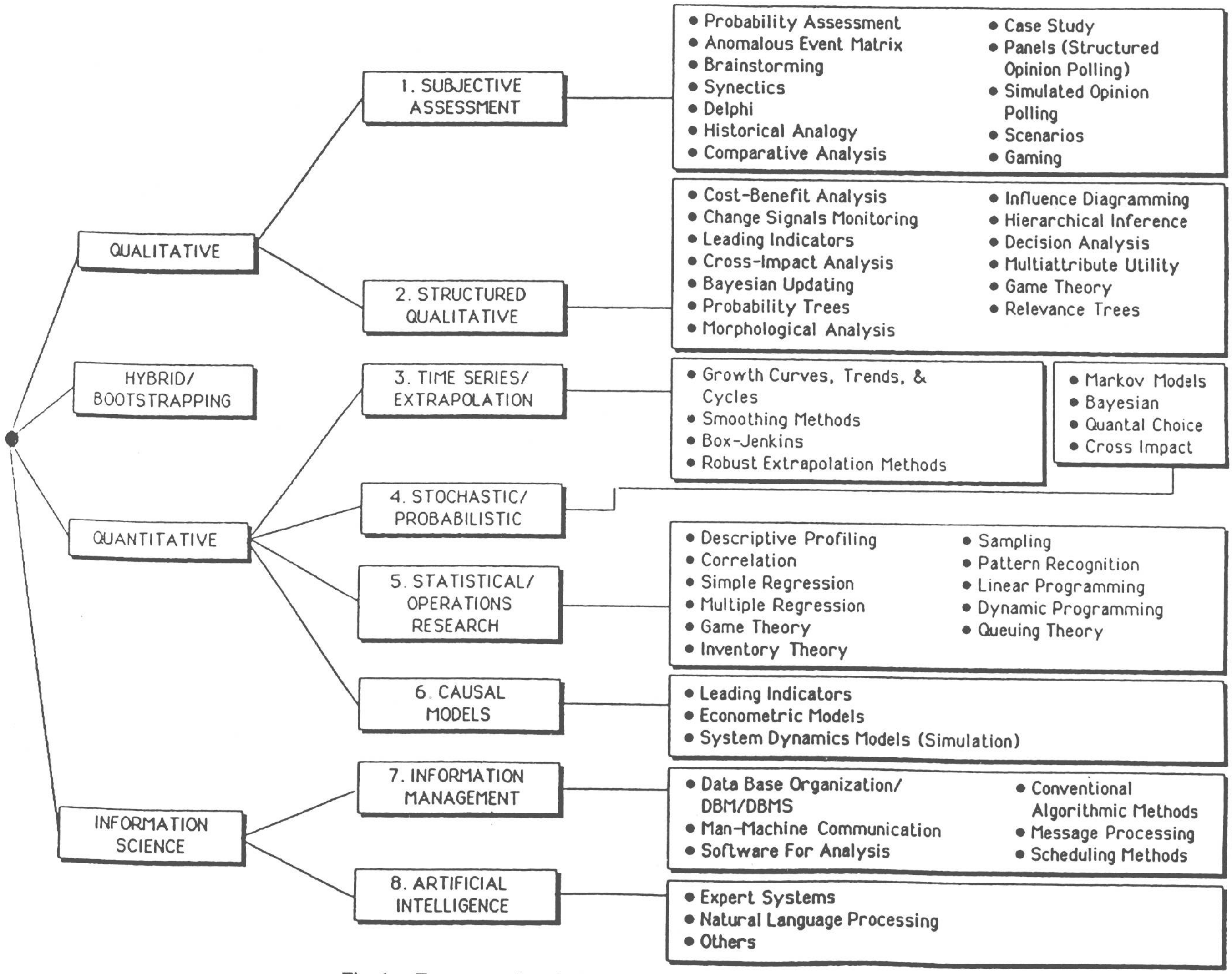


Fig. 1. Taxonomy of methods and models (after Hopple, 1986).

preferences or biases. This prediction is based in large part upon the maturation of the larger design process, which today is far too vulnerable to methodological fads. Hybrid modeling for $C^2$ systems design and development also presumes the rise of multidisciplinary education and training, which is only now beginning to receive serious attention in academia and industry.

Part II of this book looks at but one branch of Hopple's methodology tree: AI. Broadly defined, artificial intelligence systems are endowed with some knowledge about how to plan, draw inferences, and/or make decisions. Part II reprints some papers that describe efforts to design and develop knowledge-based planners, decision option generators, and data fusers. Papers that deal with the process of expert system design and development also appear, as well as at least one paper that questions the range of applied AI.

## Advanced User–Computer Interface (UCI) Technology

Twenty years ago, no one paid much attention to user–computer interface technology. This is understandable given the history of computing, but it is no longer excusable. Since the revolution in microcomputing—and the emerging one in work station-based computing—software designers have had to devote more attention to the process by which data, information, and knowledge are exchanged between the system and its operator. Millions of users now have absolutely no sense of how a computer actually works, but they rely upon its capabilities for their professional survival. A community of software vendors is sensitive to both the size of this market and its relatively new need for unambiguous, self-paced, flexible computing.

It is safe to trace the evolution of well designed human–computer interfaces to some early work in places like the University of Illinois, the Massachusetts Institute of Technology (in what was then the Architecture Machine Group, now the Media Lab), Xerox's Palo Alto Research Center (Xerox/Parc), and, of course, Apple Computer, Inc. The "desktop" metaphor, icon-based navigational aids, direct-manipulation interfaces, and user-guided/controlled interactive graphics—among other innovations—can all be traced to these and other organizations.

Where did all these ideas come from? The field of cognitive science and now "cognitive engineering" is now—justi-

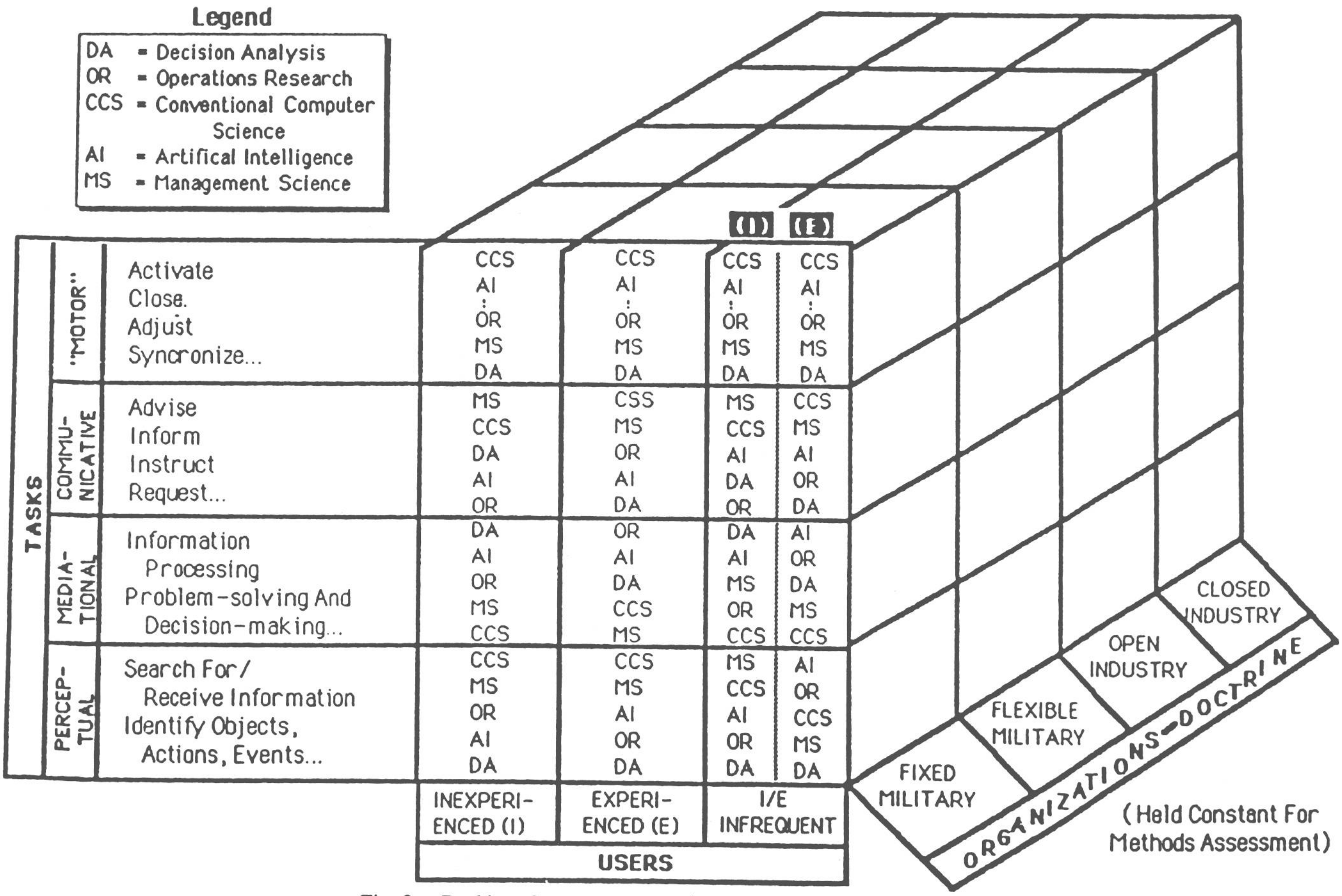


Fig. 2. Rankings for some methods/models (after Andriole, 1989).

fiably—taking credit for the progress in UCI technology, since its proponents were the (only) ones asking why the user–computer interaction process could not be modeled after some validated cognitive information processing processes. UCI models were built and tested, and concepts like "spatial database management" (from MIT's Architecture Machine Group [Bolt, 1984]), hierarchical data storage, and hypertext were developed. It is no accident that much UCI progress can be traced to findings in behavioral psychology and cognitive science; it is indeed amazing that the cross-fertilization took so long.

UCI progress has had a profound impact upon the design, development, and use of $C^2$ information and decision systems. Because many of the newer tools and techniques are now affordable (because computing costs have dramatically declined generally), it is now possible to satisfy complex UCI requirements even on personal computer-based systems. Early data-oriented information and decision systems displayed rows and rows (and columns and columns) of numbers to users; modern systems now project graphic relationships among data in high-resolution color. Information and decision systems engineers are now capable of satisfying many more substantive and interface requirements because of what we have learned about cognitive information processing and the affordability of modern computing technology.

The most recent progress in UCI technology is multimedia, or the ability to store, display, manipulate, and integrate sound, graphics, video, and good old-fashioned alphanumeric data (Ragland, 1989; Ambron and Hooper, 1988; Aiken, 1989). It is now possible to display to users photographic, textual, numerical, and video data on the same screen. It is possible to permit users to select (and deselect) different displays of the same data. It is possible to animate and simulate in real time—and cost-effectively. Many of these capabilities were just too expensive a decade ago and much too computationally intensive for the hardware architectures of the 1970s and early 1980s. Progress has been made in the design and execution of applications software and in the use of storage devices (such as video disks and compact disks [CDs]). Apple Computer's Hypercard software actually provides drivers for CD players through a common UCI (the now famous "stack"). System designers can exploit this progress to fabricate systems that are consistent with the way their users think about problems. There is no question that multimedia technology will affect the way future systems are designed and used. The gap between the way humans "see" and structure problems will be narrowed considerably via the application of multimedia technology.

Direct manipulation interfaces (DMIs) such as trackballs, mice, and touchscreens have also matured in recent years and show every likelihood of playing important roles in next-generation UCI design and development. While there is some growing evidence that use of the mouse can actually degrade human performance in certain situations, there are countless others where the payoff is empirically clear (Ramsey and Atwood, 1979; Ledgard, Singer, and Whiteside, 1981; Bice

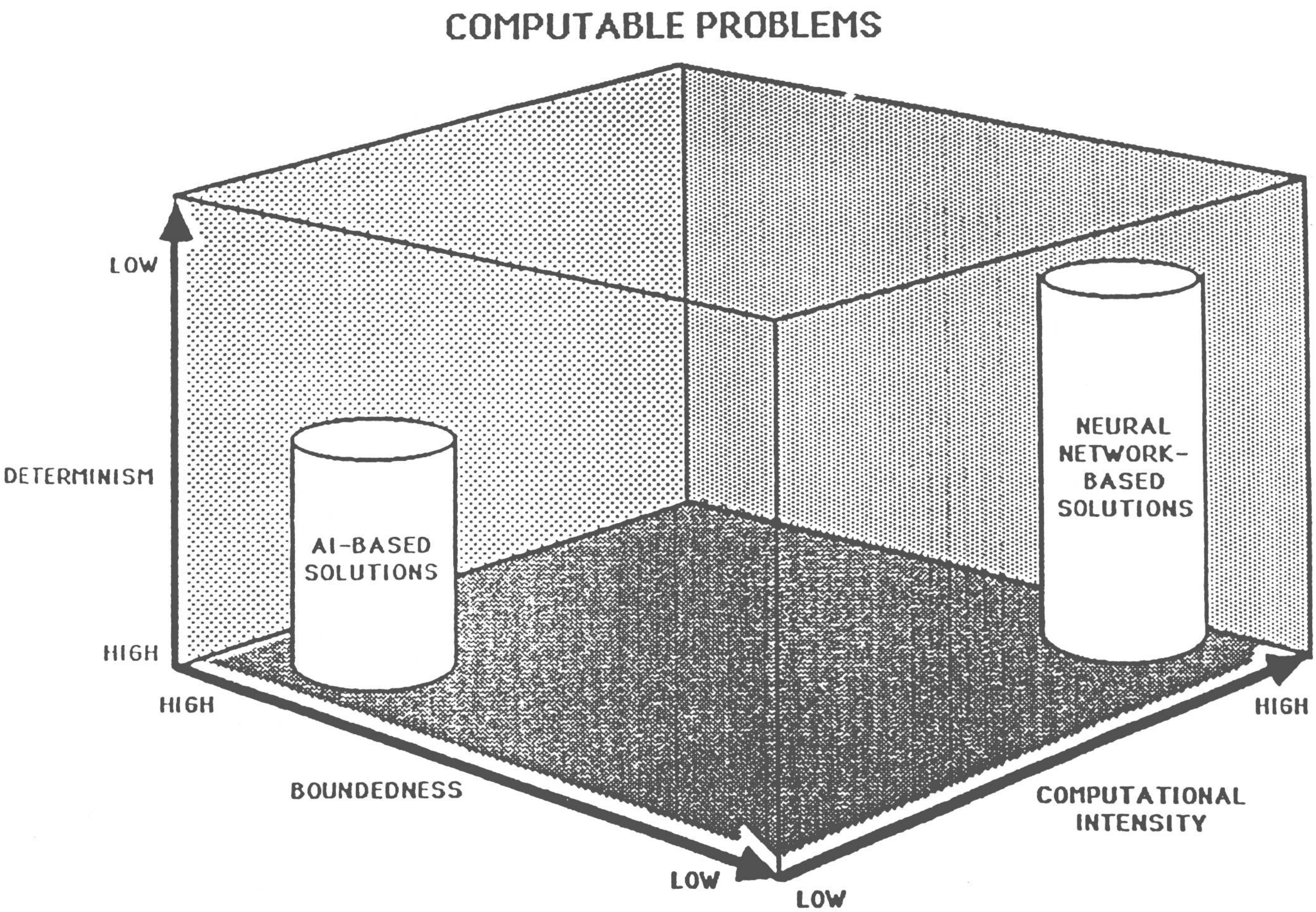


Fig. 3. Range of AI versus neural network problems.

and Lewis, 1989). Touchscreens are growing in popularity when keyboard entry is inappropriate and for rapid template-based problem-solving (Smith and Mosier, 1984).

The use of graphical displays of all kinds will dominate future UCI applications. Growing evidence in visual cognition research (Pinker, 1985) suggests how powerful the visual mind is. It is interesting that many problem-solvers are trained graphically, not alphanumerically. Military planners receive map-based training; corporate strategists use graphical trend data to extrapolate and devise graphic scenarios; and a variety of educators have taken to using case studies laden with pictures, icons, and graphics of all kinds. Complicated concepts are often easily communicated graphically, and it is possible to convert complex problems from alphanumeric to graphic form. There is no question that future $C^2$ information and decision systems will exploit hypermedia, multimedia, and interactive graphics of all kinds.

Speech input and output should also emerge over the next five to ten years as a viable UCI technology. While predictions about the arrival of "voice-activated text processors" have been optimistic to date, progress toward even continuous speech input and output should be steady. Once the technology is perfected, a number of special-purpose applications will benefit greatly from keyboard-less and mouse-less interaction.

The use of advanced UCI technology will foster a wider distribution of information technology. Early information and decision systems were used most productively by those familiar with the method or model driving the system as well as interactive computing itself. In other words, in order to exploit the technology, one had to have considerable computing expertise. Advanced UCI technology reduces the level of necessary computing expertise. Evidence suggests that training costs on the Apple Macintosh, for example, are lower because of the common user interface. Pull-down and pop-up menus, windows, icons, and direct manipulation via a mouse or trackball are all standard interface equipment regardless of the application program (and vendor). If you know how to use one Macintosh program, chances are you can use them all to some extent. Such interface uniformity is unheard of in other than Macintosh-based software systems, yet illustrates the enormous leverage that lies with the creative application of advanced UCI technology.

UCI technology will also permit the use of more methods and models, especially those driven by complex—yet often inexplicable— analytical procedures. For example, the concept of optimization as manifest in a simplex program is difficult to communicate to the typical user. Advanced UCI technology can be used to illustrate the optimization calculus graphically and permit users to understand the relationships among variables in an optimization equation. Similarly, probabilistic forecasting methods and models anchored in Bayes' theorem of conditional probabilities while computationally quite simple are conceptually convoluted to the average user.

Log odds and other graphic charts can be used to illustrate how new evidence impacts prior probabilities. In fact, a creative cognitive engineer might use any number of impact metaphors (like thermometers and graphical weights) to present the impact of new evidence on the likelihood of events.

Finally, advanced UCI technology will also permit the range of information and decision support to expand. Any time the communications bandwidth between systems and users is increased, the range of applied opportunities grows. UCI technology permits designers to attempt more complex system designs due to the natural transparency of complexity that good UCI design fosters.

Some argue that the interface may actually become "the system." The innards of the system—like the innards of the internal combustion engine—will become irrelevant to the operator. The UCI will orchestrate processes, organize system contents and capabilities, and otherwise shield users from unfriendly interaction with complex data, knowledge, and algorithmic structures.

Part III of this book presents an overview of UCI technology as well as some specific examples of how it can be applied in command and control. Papers are reprinted that deal with adaptive interfaces, hypertext, and hypermedia, and how graphics can be used to help users "navigate." The five papers constitute but a snapshot of the kinds of research, tools, and applications described above, a snapshot of the importance and power of advanced UCI technology.

### $C^2$ Decision-Making, Decision Aids, and Support Systems

Information and decision systems will be used very differently in the future than they are today. They may well function as clearinghouses for our professional problems. They may prioritize problems for us, and they may automatically go ahead and solve some of them. They will become problem-solving partners, helping us in much the same way colleagues do now. The notions of interactive systems as software and hardware, and users as operators, will give way to a cooperative sense of function that will direct the design, development, and application of the best information and decision support systems.

They will also be deployed at all levels in civilian and military organizations. Today, decision support is targeted at mid-level management; tomorrow, all levels will be supported by powerful interactive, adaptive systems. The distribution of systems will permit decision support networking, the sharing of decision support data, and the propagation of decision support problem-solving experience (through the development of a computer-based institutional memory of useful decision support "cases" that might be called upon to help structure especially recalcitrant decision problems). Efficient organizations will actually develop an inventory of problem/solution combinations that will be plugged into their decision support networks.

DSSs will also communicate with systems in other organizations in other parts of the world. Falling satellite communications costs will permit global linkages, and contact with databases, expert systems, inventories, and the like, thereby multiplying the capabilities of in-house DSSs by orders of magnitude. The global networking is not decades away, but only five to ten years away.

The most important change will occur in the way DSSs interface with other information systems. Most contemporary DSSs are "disembodied"; that is, distinct from larger corporate, government, or military information systems. Actual use of many DSSs involves leaving one system to activate another. It is common in the military application of decision support for users to work alternately with minicomputers and microcomputers, manually feeding the output from one system into the other. A good deal of this can be explained by acquisition and procurement craziness, but just as much can be traced to obsolete concepts of how DSSs should be used. As the range of DSS problems and capabilities increases, fewer and fewer systems will be disembodied; to the contrary, the most successful systems will be embedded in large organizational and executive information systems. Future systems will provide "portals" for users to explore. It will be possible to perform all sorts of tasks via myriad application programs (that ideally will have common user–computer interfaces).

The whole concept of "decision support" will evolve to accommodate changes in the larger corporate, governmental, and military information systems structure. Networking and advanced communications technology will permit linkages to databases and knowledge bases—and the routines to exercise them. Not only will distinctions among mainframe, minicomputing and microcomputing fade, but distinctions among management information, executive information, and DSSs will also cloud. Ironically, the concept of centralization may reappear, not with reference to central computing facilities but with regard to enormous systems conceived functionally as hierarchies of capabilities. Users may well find themselves within huge computing spaces capable of supporting all kinds of problem-solving. Advanced communications technology will make all this possible; users will be able to travel within what will feel like the world's largest mainframe, which conceptually is precisely what a global network of data, knowledge, and algorithms is.

The same users will be able to disengage the network and go off-line to solve specific problems. This freedom will expand the realm of analytical computing in much the same way microcomputing expanded the general DSS user community.

Finally, emerging information technology will permit designers to fulfill user requirements in some new and creative ways. Up until quite recently, technology was incapable of satisfying a variety of user requirements simply because it was too immature or too expensive. We have crossed the capability/cost threshold; designers can now dig into a growing toolbox for just the right methods, models, and interfaces. By the year 2000 this toolbox will have grown considerably. Talented DSS designers should be able to match the right tools with the right requirements to produce systems that are user-oriented and cost-effective.

The future of DSS design, development, and use is bright. While some major changes in technology and application concepts are in the wind, next-generation DSSs will provide enormous analytical support to their users. We can expect the range of decision support to grow in concert with advances in information technology.

Part IV presents a tour de force of the command and control decision-making and decision-aiding landscape. It begins with an overview paper followed by a now classic paper by Andy Sage on behavioral and organization considerations in systems design. There are several case studies as well. Decision aids for command and control have been growing in number and use over the past several years. There are now interactive decision support systems that help commanders determine the value of targets, allocate weapons, and generate tactical plans. In the corporate world, systems exist that support strategic planning, technology assessment, and resource allocation. As our computing capabilities grow and prices fall, we can only expect the design, development, evaluation, and application of interactive decision support systems to grow.

## Evaluation and Assessment Perspectives, Tools, and Techniques

The complexity of command and control begs the evaluation question. Architects and users alike often ask the only significant question: Does it work? Are mission objectives realized via the use of the system? Can we determine which technologies contribute the most to $C^2$ performance?

There are lingering questions about our overall systems engineering competence, especially when software is a mainstay of the system in question. Eyebrows were raised a few years ago when David Parnas published "Software Aspects of Strategic Defense," which is also reprinted here. The paper challenges our software engineering competence and, by implication, our ability to design or develop effective software-intensive $C^2$ systems. Other papers in Part V of the book deal with how to evaluate $C^2$ information and decision systems, how to evaluate intelligent $C^2$ systems, $C^2$ measures of effectiveness, and qualitative and quantitative methods for evaluating all kinds of information and decision systems. In addition, Part V includes an important paper on the Defense Advanced Research Projects Agency (DARPA) Strategic Computing Program, a program intended to provide a broad base of information technology support for national defense and, ultimately, national economy.

## Conclusions

Command and control is complex. It is multidisciplinary. It is also inference- and decision-making intensive. There is a variety of information technologies available to the $C^2$ information and decision systems engineer. Any list of these technologies would include those that support the requirements analysis, modeling and prototyping process, intelligent systems technology, user–computer interface technology, and evaluation methodology. The papers that follow track almost perfectly with this list. We have tried to identify those papers that most clearly address the technical issues and challenges that face $C^2$ information and decision systems engineers. At the same time, we have tried to compile a volume that will stimulate thinking about how information technology can enhance the process by which we design, develop, evaluate, and field $C^2$ systems.

## References


Aiken, P. H. 1989. *A Hypermedia Workstation for Software Engineering,* Fairfax, VA: George Mason University, School of Information Technology and Engineering.

Ambron, R., and C. Hooper. 1988. *Interactive Multimedia: Visions of Multimedia for Developers, Educators, and Information Providers,* Redmond, WA: Microsoft Publishers.

Andriole, S. J. 1990. *Modern Life Cycling: Some System Design Principles for the 90s,* Fairfax, VA: AFCEA International Press.

Andriole, S. J. 1989. *Decision Support Systems: A Handbook for Design and Development,* Princeton, NJ: Petrocelli Books.

Bice, K., and C. Lewis. 1989. *Wings for the Mind: Conference Proceedings: Computer Human Interaction,* Reading, MA: Addison-Wesley Publishing Co.

Bolt, R. A. 1984. *The Human Interface: Where People and Computers Meet,* Belmont, CA: Lifetime Learning Publications.

Hopple, G. W. 1986. "Decision aiding dangers: The law of the hammer and other maxims," *IEEE Transactions on Systems, Man and Cybernetics,* vol. SMC-16, no. 6, pp. 967–981, Nov.–Dec.

Ledgard, H., A. Singer, and J. Whiteside. 1981. *Directions in Human Factors for Interactive Systems,* New York: Springer-Verlag.

Pinker, S., ed. 1985. *Visual Cognition,* Cambridge, MA: MIT/Bradford Books.

Ragland, C. 1989. "Hypermedia: The multiple message," *MacTech Quarterly,* vol. 6, pp. 16–21, Spring.

Ramsey, H. R., and M. E. Atwood. 1979. *Human Factors in Computer Systems: A Review of the Literature,* Englewood, CO: Science Applications.

Schneiderman, B. 1987. *Designing the User Interface.* New York: Addison-Wesley.

Smith, S. L., and D. Mosier. 1984. *Design Guidelines for the User Interface to Computer-Based Information Systems,* Bedford, MA: The Mitre Corporation.

# Part I
# Command and Control ($C^2$) Information and Decision Systems Analysis and Design

THIS first section of the book presents some ideas for modeling command and control information processing and decision-making processes. It also describes some prototyping concepts and tools.

The first paper, by the late Joe Wohl, is a superb example of tactical requirements analysis. Wohl looks at the Air Force tactical planning process and identifies a set of functions and tasks that together comprise the requirements challenge. Wohl uses several models to help organize the decision process, particularly the SHOR (stimulus, hypothesis, options, and response) and Janis-Mann models of decision-making. He then turns to the relationship between tactical requirements and decision-aiding, offering ideas for decision support systems technology investments.

Boettcher and Tenney consider how to model distributed decision-making and in the process explicate requirements for submarine detection. Several information-processing models are developed and applied to the domain. Several relationships emerge, especially among team performance and individual workloads. The paper illustrates the power of information processing models and how these models can inform the hypothesis generation and testing process. The importance of such work can be traced to its contributions to theoretical insight and, through that insight, its contributions to systems design.

The third paper by Wohl, Serfaty, Entin, Deckert, and James looks at human cognitive performance in antisubmarine warfare. The subdomains are situation assessment and data fusion, but the real importance of the work lies in its contribution to understanding the cognitive processes that lead to judgments about the position and location of enemy submarine tracks and the likelihood of each in passive sonar convergence zone environments. Data was collected from experiments involving twenty subjects to refine the model, which was then enhanced via the incorporation of known cognitive limitations and biases. The antisubmarine simulation model that emerged can be used as a tool for the identification of decision-aiding requirements.

Andriole and Adelman explore the new area of cognitive systems engineering. The assumption here is that there are empirical findings from the cognitive sciences that can be leveraged in systems design, especially when combined with information technology. The focus is on the design of systems compatible with the way humans store, retrieve, display, and process data, information, and knowledge. The paper lists the key findings from cognitive science of how humans make inferences and decisions. It then presents some examples of how interfaces can be designed via insight from cognitive science and information technology (specifically, graphics, animation, simulation, and hypertext). The domain is strategic air defense intelligence and operations. The paper argues that good systems design should build upon low-level (knobs, dials, and the like) and high-level (case-based reasoning, hierarchical data storage, and heuristic search) human factors.

John Sutherland's paper, "Model-Base Structures to Support Adaptive Planning in Command/Control Systems," argues that many command and control systems have few adaptive capabilities—that is, they cannot respond to events and conditions that have not at some point been anticipated. This is an extremely important argument, since it assumes that our command and control systems may not be able to satisfy a fundamental requirement. Sutherland suggests several models that might help make $C^2$ more adaptive.

Farrell, Bonder, Proegler, Miller, and Thompson explain how to capture expertise and model command decision-making and combat analysis. Here again we find an excellent example of how models can be used to identify system requirements. The domain is the proverbial "concept of operations" and they review several models and propose some new ones. One of the models discussed suggests how qualitative judgment can be fed into a large combat simulation. Such hybrid modeling represents the kind of creative thinking necessary to solve complex modeling problems; it also represents how multidisciplinary information and decision systems engineering can yield impressive results.

The papers thus far deal with the process by which requirements can be elicited, modeled, and verified. Various information-processing models are presented in this first set of papers in Part I, and various methods, tools, and techniques are described. The next three papers in Part I (Andriole; Davis, Bersoff, and Comer; Andriole) assume that requirements have been modeled at least initially and that it is time to convert hypothetical requirements into working system concepts, or prototypes. Once the prototypes have been tested for requirements diagnosticity, full-scale development can then proceed.

Andriole describes a prototyping technique known as "storyboarding." Storyboards are the result of the requirements conversion process, a process that translates functions, tasks, and subtasks into working models of how the system might operate. Storyboard prototypes are interactive simulations of system capabilities. They are intended to display to users what the system will do; they are also intended to foster discussion about how well (or badly) user requirements have been captured in the working model. The technique has been successfully applied to a number of information and decision system design projects.

Davis, Bersoff, and Comer raise the level of analysis substantially and offer the means to compare and contrast alternative system design life cycles. The work is important because different projects have different requirements and not all life cycles will produce the desired effect. For example, if the domain was a new, complex one, in which little work had been performed previously, a life cycle that acknowledged the need for iterative prototyping might then be appropriate, just as the need for a less iterative life cycle might correlate strongly with a project restricted to several well defined system upgrades. The Davis *et al*. strategy for comparing alternative life cycles is extremely valuable and indicative of the kind of systems analysis and design research that can pay large dividends over time.

Andriole's paper, ''Flexible Life Cycling for Multidisciplinary $C^2$ Information Systems Engineering,'' integrates a lot of ideas about why life cycles sometimes fail to achieve desired outcomes. Based on the classic ''failures'' research of analysts such as Petroski, Curtis, and Lucas, the ''new'' life cycle is particularly suited to the design and development of complex information and decision systems. The paper is largely in graphic form with three cuts at the same life cycle: one is generic, one illustrates flexibility, and one suggests how the life cycle can be managed.

Collectively, the papers in Part I suggest a design and development strategy. Information processing based tools, techniques, and models, are described that help with the elicitation and description of processes that, in turn, lead to requirements definitions. The conversion of the definitions into prototypes—within larger development life cycles—provides feedback to the requirements analysis process. Although the domain is largely command and control, many of the concepts, tools, methods, and models can certainly be applied to many other domains. The discussions of prototyping and life cycling, for example, are almost generic.