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The Role of Prototyping in GIS Design:
A Case Study of the Digital Chart of the World

A Research Paper

Presented in Partial Fulfillment of the
Requirements for the Degree Master of Arts

by

James M. Giesken

The Ohio State University

07 March 1992

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Dr. Duane F. Marble
Department of Geography

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Biography

James M. Giesken
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James M. Giesken is a regular commissioned officer in the United States Air Force, holding the rank of captain. He is currently assigned to The Ohio State University as a graduate student in geography.

Captain Giesken was born February 1, 1961 in Lima, Ohio. He graduated Andrew Warde High School (Fairfield, Connecticut) in 1979 and entered the University of Connecticut. He received his Bachelor's degree in geography in May 1983 and was commissioned in the U.S. Air Force through the Reserve Officer's Training Corps. Captain Giesken's first Air Force assignment was to the Defense Mapping Agency's Geodetic Survey Squadron at F.E. Warren Air Force Base (Wyoming) in October 1983 where he served as a Geodetic Survey Team Chief and as Executive Officer until August 1986. From August 1986 to January 1988, Captain Giesken was an instructor at the Defense Mapping School, Fort Belvoir, Virginia. In January 1988 Captain Giesken became Aide to the Director, Defense Mapping Agency, subsequently serving as the Director's Executive Officer from March 1989 to August 1990. Captain Giesken attended The Ohio State University from August 1990 to March 1992 through the Air Force Institute of Technology, specializing in Geographic Information Systems.

Captain Giesken is a graduate of the U. S. Air Force Squadron Officer School, the U.S. Air Force Academic Instructor School, and the Defense Mapping School.

Captain Giesken is married to the former Christine Nelson of Newtown, Connecticut. They have one child (Jane).

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INTRODUCTION

The development and use of Geographic Information Systems (GIS) is growing rapidly as computers become more affordable and ever more powerful. Geographic Information System developers and users alike are faced with a complex array of problems during system design including definition of requirements, development of specifications, selection of hardware, and implementation of the system. Some have made poor decisions regarding these subjects in the past, often due to inadequate input into the planning process. Fortunately, recent years have seen increasing efforts on the part of developers, designers, and users to utilize structured GIS design methods to better control, define and model critical features of new systems.

The purpose of this study is to examine the role of prototyping, a software engineering concept, in the GIS design process. This study will first summarize the evolution of GIS design methodology to illustrate both its current status and how new ideas have been incorporated into the field. Then a case study will be used to evaluate the role that prototyping played in one GIS database development project and finally recommendations will be made for the further use of prototyping in GIS design.

GIS Design Issues

Proper definition and subsequent satisfaction of user requirements is the focus of the GIS design process, the same as it is for any other information system development. At present, our focus is upon maximizing the user's involvement in the design of the GIS in order to optimize the probability of delivering a workable system. Geographic Information Systems are seldom developed from scratch today and the result of the GIS design process is most often oriented toward the selection of a system that matches the users' requirements from a set of GISs offered by competing firms. However, the development of GIS databases and applications also require substantial levels of system design activities.

Of course, insertion of the human factor into the design process brings forward a set of social and organizational obstacles to the definition and implementation of user requirements. One way of coping with these constraints is to introduce a structure into the GIS design process to best account for foreseeable problems. Calkins (1972) was the first to develop a structured GIS design process that was systematic and, to an extent, repeatable. It offered general guidance on the activities to be performed and thereby increased the chances of successful GIS implementation. Since Calkins, others have introduced more advanced GIS design processes which take into account new approaches to system analysis. Some designers have called for incorporating specific software engineering techniques such as structured system analysis and modern database modelling into GIS development. Although there was some early resistance, these ideas are now being readily accepted and implemented.

One such software engineering technique, called *prototyping*, has come to the fore in the realm of software system design. Early on, prototyping in software development was used primarily during coding operations as a technique for the identification and removal of design defects in software implementation activities (Carey and Mason, 1983). It is now more often defined as a process of modelling user requirements in one or more levels of detail, including working models (Pressman, 1982). A procedure known as *rapid prototyping* illustrates the greatest advantage of the prototyping process but is often overlooked in system design projects. Rapid prototyping uses a rapid pace to quickly gather information about initial requirements and is a specific strategy for the subsequent refinement of user requirements through modelling (Peters, 1981; Connell and Shafer, 1989). In either case, prototyping or rapid prototyping, the goal is usually to derive a working piece of software (Pressman. 1982; Connell and Shafer, 1989).

Given the tendency of some in the GIS field to resist the introduction of new software engineering techniques, it should not be surprising that prototyping is not wide spread in GIS design and implementation. A notable exception is the Marble-Wilcox GIS Design Model (1991) which is explicitly based in modern software engineering methodology and includes the option of utilizing pilot studies to aid in the determination of user requirements in certain situations. However, pilot studies are defined by them as "a sample implementation of the proposed GIS within a well-defined but limited test realm" (Marble and Wilcox, 1991) which is intended to focus user requirements and prove that the initial design is, at least, feasible. Because pilot projects at the system level are often expensive and require pre-selection of GIS software for demonstration purposes, they are not frequently performed.

Although pilot studies in GIS design and prototyping in software engineering can both be utilized to focus user requirements, there are subtle differences between them. Pilot studies work toward a larger goal, that is the refinement of the proposed system configuration, by assessing the required user functions, costs, data availability, and by taking a first look at performance requirements in a sample implementation. Conclusions from the sample implementation are used to refine the requirements analysis process and the system design and specification documents. Prototyping in software engineering is commonly focused upon the implementation of a piece of software. Several iterations of the prototyping cycle usually lead to a running version of the software, ready for release (Pressman, 1982).

While much has been written about the importance of involving users in the design and implementation of GISs, there is a pressing need to learn more about the way in which GIS users and developers interact during the design of a Geographic Information System. There have been few efforts to document the results of the system design process in Geographic Information System development, regardless of methodologies used. In most instances, developers are content to conduct the design and implementation work, with or without the user's active involvement, deliver a system, and then go about their business. Their concern is not whether the specifications were adequate but whether they were available. Once the system is in the user's hands it is no longer one of the designer's top priorities.

Peuquet and Bacastow's recent article (1992) is one attempt to record the results of the design process. They show how the organizational context of the U.S. Army's effort to develop a GIS has prevented successful implementation to date; technological issues have proven to be less of a hindrance. They recommend the use of iterative prototyping as a way of overcoming obstacles in satisfying user requirements. While prototyping is not new to many disciplines, especially the engineering fields, it is not widely used in the development of GISs. One can find few references to projects where prototyping has been used; those that do exist are primarily in the Management Information System design literature (Connell and Shafer, 1989). One significant case that does exist within the realm of GIS design is the Defense Mapping Agency's

(DMA) Digital Chart of the World (DCW) database development project. Examination of this case can provide a good starting point for further investigation into the use of prototyping to enhance GIS design methodologies.

Problem

Given the importance of user involvement in the GIS design model, the traditional form of design methods such as structured analysis and the Marble-Wilcox Design Model, and the tendency to infrequently rely on iterative development of requirements, what role can prototyping play in GIS design and implementation? This paper will strive to answer this question by first looking further at GIS design issues, the relevance of prototyping as it has been applied to system development, and finally by studying a case where prototyping was used as a major tool in the design of a large GIS database.

Overview of Study Methodology and Scope

After a review of current literature in GIS design and software engineering fields, this study will present a descriptive and exploratory case analysis of the Defense Mapping Agency's Digital Chart of the World development project to provide insight into the GIS design process and the adoption of a rapidly growing technology (GIS) in the unique arena of the Department of Defense. The impact of prototyping on the DCW design will be examined in depth. Specific areas of concentration will include an analysis of the processes by which user requirements were defined and met, the problems associated with the implementation of prototyping, and how prototyping may help the GIS design process.

Review of project documentation and interviews with personnel involved in the design, production, and evaluation of the prototypes provided the bulk of the research data. Project documentation was made available by the DCW sponsor, the Defense Mapping Agency, and its contractor, Environmental Systems Research Institute (ESRI). An extensive review of these documents led to an interview plan for site visits to follow up on issues discovered during preliminary research (the interview plan used during the site visits is contained in Appendix 1). Two site visits were conducted to personally interview major participants in the DCW development project.

The first visit to Washington, D.C. in August of 1990 was for the purpose of contacting personnel from the Defense Mapping Agency, the sponsor of the project. In addition, the proximity of various military commands, services, and defense agencies in the D.C area provided an additional opportunity to interview the users for whom the product was being developed. The second visit was conducted at the Redlands, CA site of ESRI, the firm doing the DCW development work under contract with DMA. This visit allowed for in-depth discussions with various production personnel as well as the chance to obtain additional documents regarding the design and implementation of the DCW program. A list of persons contacted for this study may be found in Appendix 2.

The bulk of this report was compiled after reviewing the project documentation and collating the vast amounts of information provided in the interviews into a set of relevant material. The organization of this study will lead us through a process where we will:

- Learn about the current status of system design activities (chapter 2);
- Discuss the case study of a GIS database design project and highlight factors important to our understanding of the case (chapter 3);
- Examine the way in which the development project was executed and how the participants' reacted to the project (chapter 4); and
- Summarize how prototyping may be used in GIS design by looking at findings, recommendations, and future work (chapters 5 and 6).

CHAPTER 2

LITERATURE REVIEW

The GIS design literature stresses the need for active user involvement in the design and development of systems, databases and related products. There are many methods which may be used to accomplish various objectives in any information system design process but most are now structured in some formal fashion (see Yourdon, 1989 and Connell and Shafer, 1989 for general system design; Marble and Wilcox, 1991 for a structured approach to GIS design). The use of prototypes has long been an accepted method of system design in other fields but has not been widely recognized inside information systems development, nor in GIS design, until recently. Prototyping elsewhere has demonstrated strong potential, especially in small project development.

A review of the current state of GIS design and software engineering techniques serves as a starting point for an investigation into how prototyping can be used in GIS design.

User Needs Analysis

Regardless of the level of credence given to the adoption of software engineering techniques in the GIS design process, user participation has been stressed throughout the 1980s and the early part of the 1990s by numerous authors involved in GIS research (Chrisman, 1987; De Man, 1988; Marble and Wilcox, 1991). The first steps of the Marble-Wilcox GIS Design

Model deal explicitly with defining and considering the organizational concerns and user requirements which "underlie the entire purpose of not only the design process, but of the GIS implementation itself" (Marble and Wilcox, 1991). Such studies of requirements and organizational impacts are very complex, not completely understood, and can change along with the composition of user groups in each project and with advances in technology (Eason, 1988; Rhind and Green, 1988; Teory and Fry, 1982).

It can be taken as a given that organizational concerns accompany the adoption of any new technology such as a GIS (see Eason for a full discussion of problems associated with the adoption of new information technology). In addition, failure to adequately involve users in the system design process often leads to numerous, varied, and complex organizational and institutional problems. This second set of problems alone often can cause failure of an information systems development project (see Lucas, 1975; De Man, 1988; Eason, 1988 for illustrations of these concerns).

Early identification of these concerns is one way to mitigate the chances of failure. Actively involving the user in the design process, including the definition of organizational issues, encourages maximum interaction between designers and users. This helps the designers deliver a beneficial product and aids in convincing the users that real advantages will stem from adoption of the new technology (Marble and Wilcox, 1991). This also sets the stage for a more fruitful exploration of user requirements.

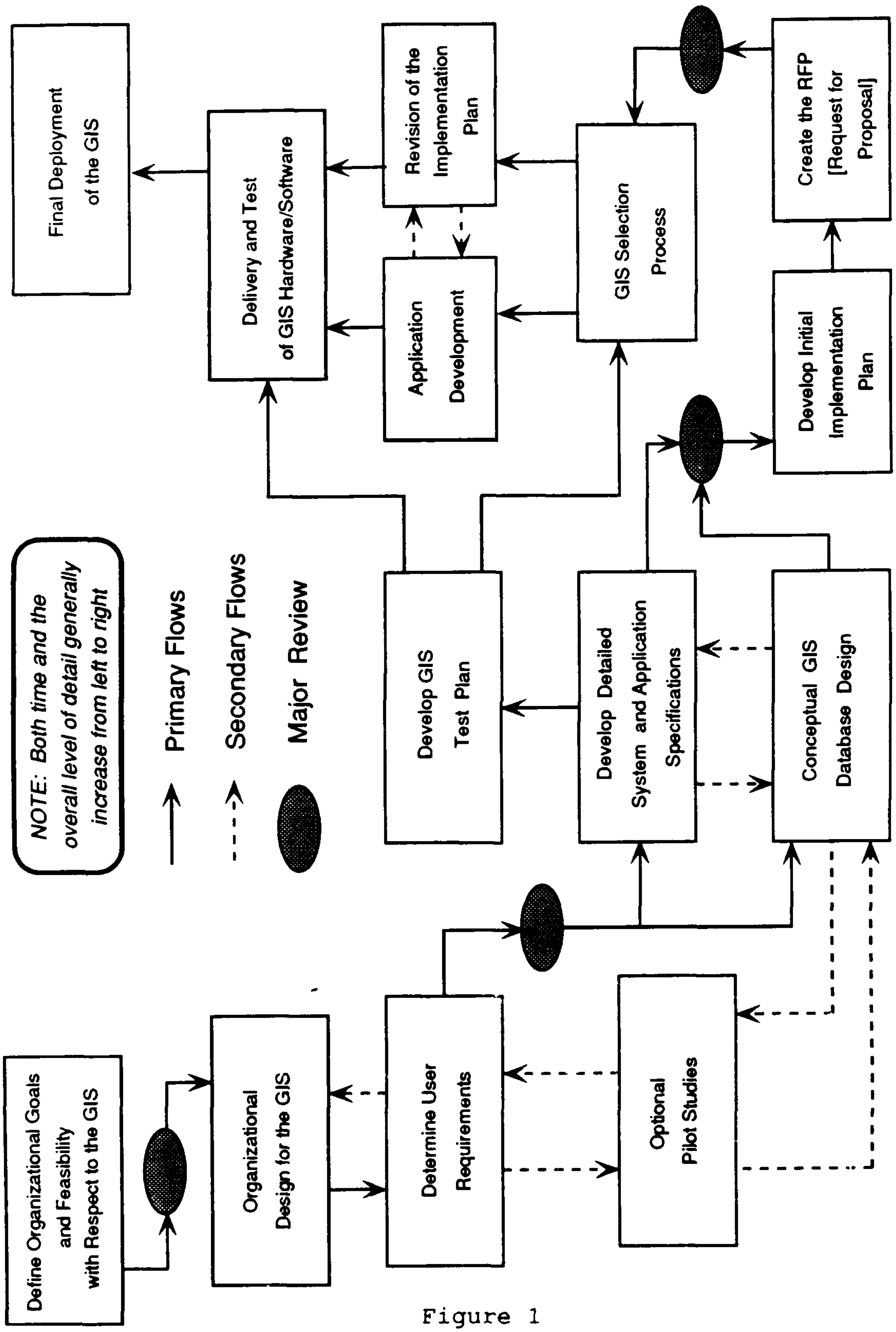
There are many bottlenecks and barriers to the effective functioning of an information system within the larger information utilization system inside of which it must function. Potential information flows to and from the system, organizational procedures and needs, and actual uses of information are all important foci (De Man, 1988). Organizational and institutional changes often are required to handle the increased emphasis on the new technology. De Man addresses structured approaches to system design but goes on to impugn their usefulness by asserting that these methods are too rigid and fail to recognize the uncertainties of change and the dynamics of an information system's environment. Lucas (1975) adds a fresh dimension to 'old stand-by' rules in his work on design strategies. He lists seemingly obvious factors regarding organizational interaction in information system design that are often over-looked in Geographic Information System design. Lucas develops a descriptive model of information systems within the context of organizational behavior (focusing on user attitudes and perceptions, the use of systems, and user performance). The author's conclusion that management holds the key to carrying out user-oriented design is right on the mark. Good managers will see to it that the design activity works for the user (Lucas, 1975), even in the rapidly changing environment De Man addresses. While the author makes this case in a low-key fashion, the message is one which should occupy a place of prominence in the minds of all GIS analysts.

Eason's (1988) main assertion is that introduction of any information system technology will change an organization. To make the change as effective as possible, the organization should be altered to take into account the new technology. He advocates a structured approach toward design and implementation of information systems to ease this transformation. There are several ways of doing this which include structured design methods, participative design methods, and even end-user developed systems. Eason argues for a more "socio-technical" design method that incorporates some of the best features of each of the preceding methods. User-oriented design techniques are the most favored method. Eason argues that in order for an information system to work well, it must first fulfill the organization's needs on a technological level, but the people who will interact with the system must view it as an important tool which will aid their efforts. Without development of this latter view, the system will likely fail due to lack of use or even outright sabotage (Eason, 1988).

After the decision is made to develop or acquire a new system and the relevant organizational concerns have been addressed, the formal definition of user requirements may begin. This is a detailed investigation into the essential specifications of what the system is supposed to do (Yourdon, 1989). Involvement of the user can take many forms but it is most helpful when designers have an in-depth understanding of the user's actions, data transformations, and work environment. Structured methodologies and software engineering practices have proven invaluable in performing these tasks. Surveys, interviews, and working sessions, where the users actions are observed, all play an important role in this process. Pilot studies are highly useful and can be related to prototyping. These projects allow the user to move from the "abstract to the specific in contemplating uses of the GIS" (Marble and Wilcox, 1991). Further design of new systems, where we move from a conceptual model of the system to a physical implementation (and including development of prototypes), relies heavily upon the adequacy and accuracy of these requirements.

Efforts to develop a GIS design methodology have closely followed evolution of software life cycle models. Boehm's classic waterfall cycle (1981), Calkin's work, and modern structured techniques such as Yourdon's all offer this perspective. A GIS design methodology which has been heavily influenced by software engineering techniques can best be represented by the Marble-Wilcox model. The Marble- Wilcox model is a traditional step-by-step approach which uses an iterative cycle to define useful guidelines in addressing design and implementation questions. Figure 1 shows the Marble-Wilcox model, and its flow from the feasibility study to the definition of user requirements, construction of the database, development of system specifications, and other critical concerns. The influence of the "waterfall life cycle model" and other software engineering concepts is unmistakable (it is also systematic, repeatable, and flexible).

As affordability and advances in system capabilities allow more and more users to take advantage of GISs on a wide variety of computer platforms, broader design concerns come into play such as how to construct GIS databases for a myriad of users. Very large spatial databases are becoming more feasible as technology improves and costs decline; however, issues associated with system design become even more important in these large cases since small problems will be magnified. Epstein's article in the book *Building Databases for Global Science* (1988) illustrates the need for specific goals when developing large global data sets by outlining some of the obstacles to such a feat. The fact that databases do not exist in environmental and conservation forums is probably due to the lack of a clear and achievable purpose. Epstein shows that large sets of digital information can indeed be collated and used by a number of customers effectively within specific information regimes. As we shall see in the next section, it seems reasonable to assume that the techniques for user requirements definition offered by structured methods coupled with prototyping activities may provide a way to assimilate the requirements of multinational organizations into a user-oriented design document, thereby increasing chances of success in the development of a global database.



MARBLE - WILCOX MODEL: GENERAL FLOW DIAGRAM

Source: Marble and Wilcox, 1991

Figure 1

Prototyping in Software Engineering

Prototyping is the process of modelling the users' system requirements by creating working models at increasing levels of detail (Boar, 1983). After models of the system are built by stepping through physical implementation activities, the user may then review the design and provide feedback to the process (Pressman, 1982; Krista and Rizman, 1989). Prototyping can be used for mass-produced, as well as one-of-a-kind, systems. Mock-ups and prototype models are often used during the development efforts associated with many conventional engineering fields (Peters, 1981) whereas software developers and GIS designers are seldom trained in such a fashion.

The concept of prototyping in software engineering has evolved from an implementation activity to one more focused on the conceptual stages of design. Early ideas called for the use of prototypes to design, implement, test and bring into operation a highly simplified version of the system according to a defined set of user requirements. Based upon the experience gained in operating the first prototype, a revised requirement was established and a second prototype was designed and implemented (Bally, Brittan, and Wagner, 1977). The activities associated with this type of prototyping include fairly detailed requirements analysis and system design. Use of prototyping in this fashion, as well as to detect and remove design defects in coding operations, is an implementation activity (Carey and Mason, 1983).

Recently, software engineers have called for prototyping to be used as a specific strategy for the definition of user requirements and the revision of those needs through iterative analysis activities (Peters, 1981; Sethi and Teng, 1988). A recent outgrowth of prototyping, known as rapid prototyping, makes use of an accelerated pace to swiftly gather data about initial system requirements. This rough analysis is then used to build models for the users' review and comment. Successive iterations refine and revise user requirements and lead to a system specification document for the final product (Connell and Shafer, 1989; Arthur, 1992). Prototyping in this manner, whether at a rapid pace or not, may be used to bridge the gap between requirements analysis and system design and implementation.

Peters (1981) argued that prototyping could be used to objectively establish the quality of the design by evaluating user feedback. Some of the advantages to this approach, as put forth by Arthur (1992) are:

1. More effective communication between designers and users.
2. Reduced risk of failure due to less uncertainty.
3. The ability to deliver the desired functionality.
4. Serendipity in the development process can be maximized.
5. Reduced cycle time by a factor of four or more.[1]
6. Fewer defects through continuous testing and evaluation.
7. Users are more involved.

Pitfalls may include an inability to manage the expectations of users brought about by their interaction with the prototype and a tendency to omit key players or to involve too many reviewers. Prototyping was greeted by considerable resistance when first introduced on a wide scale as an evaluation technique in software design (Peters, 1981; Connell and Shafer,

[1]Arthur (1992) stated that cycle time "from concept to delivered product" may be reduced by a factor of four or more by focusing on creating only the parts of the product that provide the most value. He equates it to gaining 80 percent of the value by expending only 20 percent of the effort on the first prototype.

1989). While computer information scientists remained unconvinced of its utility in the early 1980s, there was one critical study where the advantages and disadvantages of prototyping were clearly demonstrated (Boehm, Gray, and Seewaldt, 1984). In this study, a software product was developed by teams taking two different approaches; several teams used the more traditional top-down specification development approach while the others used prototyping.

The results of this experiment indicated that prototyping offered several improvements to the development process for software products. Prototyping turned out products equivalent to the specified product but with nearly half the amount of code and with nearly half the effort. While the specified product was somewhat more easily designed, integrated, and coded, the prototyped product had a "more friendly" user interface and was easier to learn how to use. However, prototyping required that more time be spent on testing, fixing, and integrating modules according to user feedback rather than defining requirements (Boehm, et al., 1984).

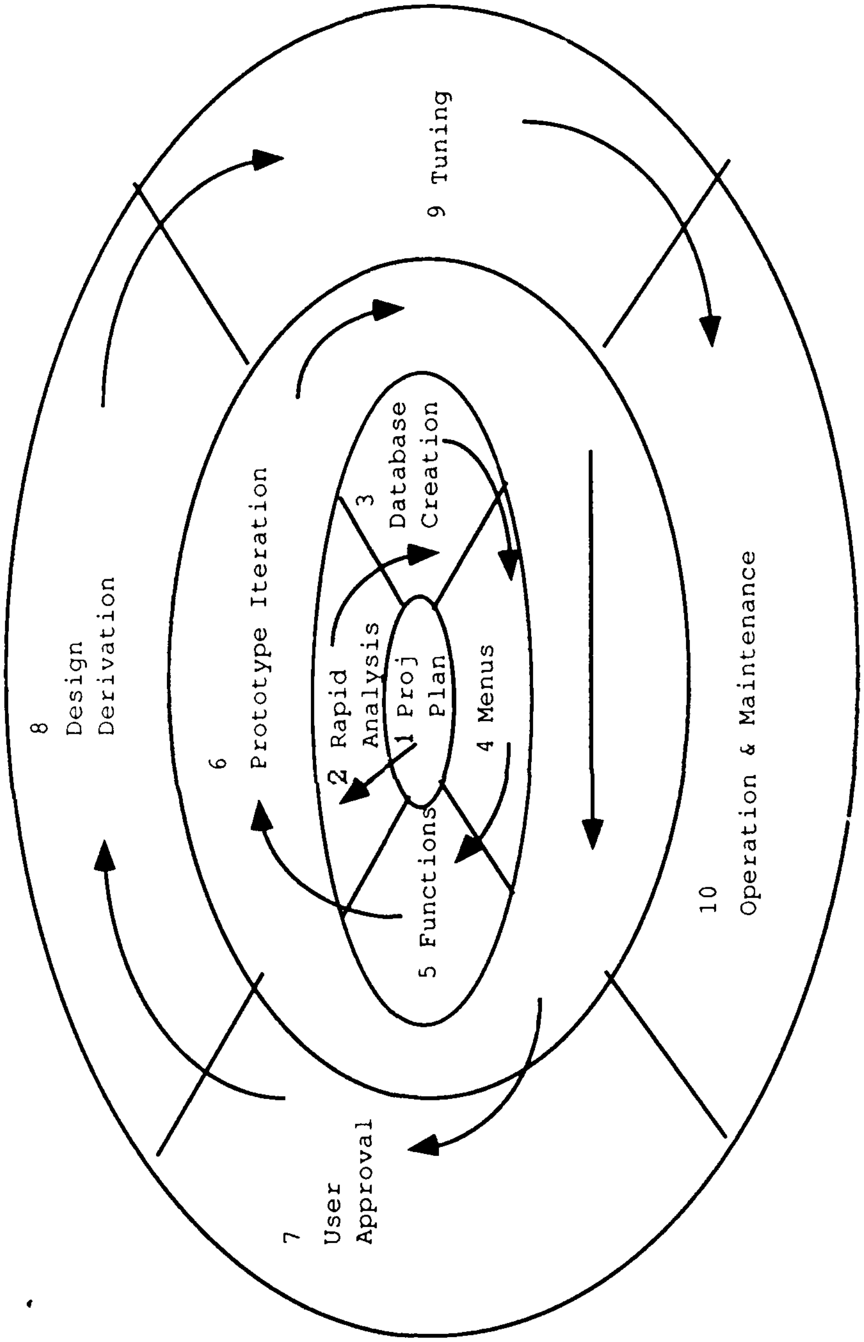
This study, however, focused on the designers of the software, neglected any measure of user satisfaction with the product, and paid little attention to the costs associated with the reviewers' investment in the process. In addition, the prototyping process was geared toward making the designers, coders, and testers' lives easier, not toward demonstrating products to users to aid in requirements definition and evaluation. Despite recent calls for the use of prototyping as a requirements analysis and design technique, software engineers tend to remain focused on implementation activities.

Connell and Shafer (1989), in their recent volume *Structured Rapid Prototyping* explained that prototyping must be coupled with structured design methods in a fast paced environment to achieve its full potential. Their arguments for tools linking structured system analysis techniques and relational database management systems illustrate how software structures can be changed quickly to accommodate user's reactions to prototypes. The focus here is to quickly gain only a rough idea of the system requirements at first, construct prototypes using these tools to help the user better define their true needs in iterative steps, then refine the design documents before moving on to the physical implementation of software.

Connell and Shafer's suggestions provide for a modified design life cycle using data flow diagrams (DFDs), entity-relationship diagrams, and control flow graphs (to model the user's menu interface), along with an evolutionary approach to speed development in many ways. Their modified life cycle is included as Figure 2. Connell and Shafer argued that a new life cycle approach to software development may seem to call for conventional activities to occur at unconventional times, especially since the process is not sequential, as the figure implies. Anything discovered during prototype iteration must be immediately addressed, wherever it occurs in the cycle.

The first activity in the Connell and Shafer model is to produce a document of rough schedules and deliverables (step 1). Next, preliminary interviews with users are used to create an "intentionally incomplete, high-level paper model of the system" (Connell and Shafer, 1989) and a partial requirements specification (step 2). The database, menus, and functions are created in the next three steps to produce a model for demonstration to the user. At this point, fourth-generation techniques can be used to link Computer Assisted Software Engineering (CASE) tools to Relational Database Management Systems (RDBMS) to develop forms, screens, menus, and reports in a working prototype for the user's review (Connell and Shafer, 1989).

Connell and Shafer's Evolutionary
Rapid Prototyping Process



Source: Connell and Shafer, 1989

Figure 2

One of the tools used in Connell and Shafer's approach to prototype creation is the control flow graph (CFG). CFGs and other products of the CASE tool serve as a bridge between requirements analysis and system design activities. Where Data Flow Diagrams model the flow of the data and its transformations, in the system, CFGs illustrate the user interface by modelling the menu structure of the prototype. Symbols on the CFG represent buttons on the proposed menu interface and can be linked to what will happen during execution of the system modules. A realistic demonstration of the interface can be accomplished by using CFGs, tied to a RDBMS, to query a preliminary database and show the user the results of the actions taken by pushing menu buttons. Data Flow Diagrams, and Entity-Relationship Diagrams (ERDs) remain available for discussion with the user about how the system will carry out these functions, if necessary.

User comments on the first prototype are then included in subsequent prototype iterations, step six on the diagram (figure 2). Recursive actions may occur throughout the model up to this point. Once the final prototype has been accepted by the user (step 7) a preliminary system design document is generated using the DFDs, ERDs, and CFGs developed in the prototyping phase. This is followed by fine tuning, implementation, testing, and operation and maintenance (steps 9 and 10).

Connell and Shafer's ideas are especially well suited to database design projects because of the linkage of CASE and demonstration tools to the RDBMS. Many individual user views of the database could be easily assimilated into a global view for further design activities using Connell and Shafer's methodology. The application of this procedure to the challenge of developing global data sets for multi-national users is particularly promising. The importance of modelling the user interface in Connell and Shafer's rapid prototyping approach also makes it an ideal candidate for use in system application development projects, including GIS applications. Some modification of the interaction with the user during demonstration of the prototype would be required due to the nature of the spatial data and output characteristics of GISs. Any small project where time is a critical factor and where initial requirements are not well defined are also good candidates for rapid prototyping.

One important component of prototyping that Connell and Shafer stress is the communication element. Users must have a clear understanding regarding their responsibilities to be productive members of the prototyping team. These responsibilities must be spelled out in a project plan before work is started. If the project plan is made available to all prospective users, many misunderstandings can be avoided and the disadvantages to prototyping will be lessened.

The use of prototyping is currently in a transition within the software engineering field. Although most traditional uses of prototyping include activities focused upon software development and implementation, many software engineers are moving toward the use of prototyping throughout the design process, especially in the critical area of requirements analysis.

Linking GIS Design and Software Engineering

Marble (1983) was the first to call for "drawing upon some of the concepts and tools developed . . . in the field of software engineering" to advance GIS design. However Marble and Wilcox (1991) continued this initial work by arguing that several crucial differences "separated GIS design activities from those in software engineering." The focus of software engineering techniques on the creation of working code was one critical factor. The GIS design process is primarily intended to aid in the selection between "competing and complex spatial data handling systems" (Marble and Wilcox, 1991). However, recent suggestions in the software engineering literature to use prototyping primarily as a requirements analysis tool and to later focus on implementation activities may overcome some of the obstacles to its use as noted by Marble and Wilcox.

One example of a GIS design project where prototyping was used can be found in the Defense Mapping Agency's GIS database development project, the Digital Chart of the World. An examination of this case may help us clarify the role of prototyping in GIS design.

CHAPTER 3

AN OVERVIEW OF THE DIGITAL CHART OF THE WORLD PROJECT

Within the Department of Defense (DoD), there is an increasing base of GIS users who have been eagerly adopting GIS-related technology on an ad hoc basis. Many of these users have focused upon their own specific circumstances in order to contract directly with vendors for geographic information systems geared toward their own supposedly unique situations. The Defense Mapping Agency (DMA), the entity within the DoD responsible for producing, maintaining, storing, and distributing maps, charts, geodetic data, and related products for the department, was often omitted from these processes. Recently, over one hundred contracts for digital versions of traditional paper maps were let in the Department of Defense without DMA oversight (Digital Products Study, Summary Report, 1991) This omission was contrary to DoD directives but can be traced to the fact that DMA did not produce topologically structured data for use in GISs.

This situation has led to a proliferation of GISs in a wide variety of organizations, with each often requiring data sets in unique formats in order to operate. The GIS acquisition process has mirrored the development of the now prevalent "smart" weapons systems (cruise missiles, guided munitions, etc.) in the 1970s and 1980s many of which rely upon digital geographic data (non-topologically structured raster and vector data) for navigation and targeting capabilities. During this period, databases for very specific digital products were developed and acquired, at great expense in time and money, for each weapon system requiring digital data. The result was a cumbersome structure for acquiring data in various digital forms wherein the producer often transformed one data set into another format for use in another system.

The Defense Mapping Agency, in an effort to forestall such a fragmented approach to the development of GIS in DoD, has undertaken an effort to develop a standard for digital vector data and a sample digital database through a development project called the Digital Chart of the World (DCW). Their recognition of the importance of GIS technology to their users, and their entry into the world of GIS by explicitly supporting the users with data, is a significant milestone in the advancement of GIS within the Federal establishment. The well defined organizational structure of DoD, the public availability of the DCW, and the use of an innovative design process offer a unique opportunity to study the role of prototyping in the development of the database component of a GIS, the interactions between DMA and its customers in the department, and DMA's first efforts to support users of GIS.

It is important to note that this study relates to the development of a digital product based upon a traditional cartographic map database and does not deal with the implementation of a new technology. Rather, it deals with an attempt by an organization to involve users in its effort to begin production of topologically structured data sets. Before we begin to look at the specifics of the DCW development process, we will first present some background information pertaining to DCW, then attempt to obtain a better understanding of how DMA functions in order to be better able to understand the DCW case.

The DCW Project

The DCW began in October 1989 as a research and development project with two objectives. Since DoD units were increasingly using GISs, the first goal was to develop a "suite of standards" for the collection, formatting, and exchange of topologically structured digital vector data (Statement of Work (SOW), 1988). The "suite of standards" subsequently became known as the Vector Product Standards (VPS) and was primarily intended to allow DMA's customers to use common data, whether it was acquired through DMA or a contractor. The second goal was to build a sample global database at the 1:1,000,000 scale according to these standards.[2] Originally, these two goals shared equal priority (SOW, 1988); later documentation stated that this DCW research and development project "has as its primary goal the development of Vector Product Standards (VPS) for the provision of digital geographic information to Department of Defense (DoD) and Intelligence Community activities" (Danko, 1990). The changing priorities with respect to these two goals had a significant impact on the progress of the development effort and will be examined in later sections of this paper.

The VPS standard developed as part of the DCW project is designed to serve as a basis for all future GIS products produced in the Department of Defense (Lang, 1992). All DoD users of vector-based GIS products will be required to conform to the VPS. A variety of digital data standards already exist in DoD but are focused on the exchange of data between cartographic data producers such as DMA, the United States Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), and various foreign producers.

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[2] Bickmore (1988), in *Building Databases for Global Science*, suggested the creation of a digital base map of the world showing topographic relief at the 1:1,000,000 scale.

DMA's "quest [was] to establish standards that will be embraced by the community of customers" and will be used by its customers for "the collection, formatting, and exchange of digital geographic information" (Danko, 1992). The standards were required to be user oriented and to work in a variety of computing environments with a variety of vector data (SOW, 1988). In other words, the standards were not to be tied to any one product but should allow specifications for new products to use the standards in order to generate vector data in a standard format. The standard for the data format, known as the Vector Product Format (VPF), formed the heart of the VPS "suite of standards" and was explicitly targeted towards users who individually contracted for the production of data sets (see Appendix 3 for a summary of VPF).

The DCW database produced during this development project is a medium-scale digital vector database obtained by digitizing the Operational Navigation Charts (ONCs). The ONCs are the largest scale product in the DMA inventory with world-wide coverage (except Antarctica) and are cooperatively produced by many countries. Since ONCs do not include all of the world's landmass, six Jet Navigation Charts (1:2,000,000 scale) were used over Antarctica to provide complete coverage. Several factors led to the decision to use ONCs to produce a global database in conjunction with the development of the Vector Product Standards. The first was the stated need by DMA to provide a wealth of data in the proposed format to "attract the users and promulgate the standards" (Danko, 1990). There was also a stated need "throughout DMA and the entire Mapping and Charting community for a global database at a small scale" (SOW, 1988). It is interesting to note that this latter need statement begins by identifying DMA as one of those who need the database and then moves to the normal object of DMA's attention, its customers throughout the DoD.

The Digital Chart of the World database provides standard topographic information consistent with 1:1,000,000 scale map products, including elevation contours, transportation routes (roads, railways, canals, etc.) populated places, drainage, coastlines and international boundaries (Danko, 1992). Some information is missing for certain features on the base map of the ONC due to the primary intended use of the charts (aerial navigation). In these cases, data were added to the DCW database from other sources. For example, roads are not connected through cities on ONCs because the intended use for the product called only for city outlines which might show up on radar return displays. Roads were connected through city outlines in the DCW database using alternative sources. A complete list of thematic layers included in the DCW data base follows:

Table 1
DCW Thematic Layers
(DCW Interim Product Specification, 1991)

Aeronautical Data	Political/Oceans
Cultural Landmarks	Populated Places
Data Quality	Railroad
Drainage	Road
Hypsography	Transportation Structure
Land Cover	Utilities
Ocean Features	Vegetation
Physiography	ONC Index

A digital gazetteer also is included which allows one to display place names on the database display (DCW Interim Product Specification, 1991).

Four countries, Australia, Canada, New Zealand, and the United Kingdom, fully participated in the project as the cooperative producers of the ONC series as well as potential users of the topologically structured global database (Danko, 1992). The map and chart producing agencies from these countries acted as DMA customers in this project and augmented the base of U.S. DoD customers involved in reviews of the prototyping effort. Though the foreign users provided half of the initial review group, this study of the organization and interaction of this customer base during the DCW project we will only focus upon the U.S. users. The U.S. users were the only personnel accessible for interviews.

Organizational Context of Department of Defense Units Involved in Mapping

Before we launch the case study, it is important to understand the changing world in which DMA is operating because this external environment affects the definition and satisfaction of requirements levied upon DMA. Traditionally, DMA has been a giant map factory, spitting out massive amounts of paper maps and charts, geodetic data, and digital data intended for specific purposes. The agency responds to input from its "customers," that is the combat commanders from all branches of the military and the services individually (in their role as trainers and weapon system developers). Communication in the military system flows up and down the "chain of command" in a formal fashion and is sometimes fragmented and incomplete and is supplemented by informal information which is often passed horizontally between units of different commands. Communication between DMA and its customers is no different. A large, well understood bureaucratic system has evolved over time to carry out the military mapping mission.

To aid our understanding of the issues involved in the development of the DCW one must know how the Department of Defense is structured and how the various entities within the department interact with DMA. After delineating the structure of the department and the role of the commands, services, and service laboratories in mapping affairs, we will examine the way in which DMA operates.

Structure of the Department of Defense

The Department of Defense is a large organization with very well-defined roles for many of its subordinate elements. The Secretary of Defense sits atop a structure of under secretaries and assistant secretaries responsible for various aspects of defense policy. The Joint Chiefs of Staff are the secretary's military advisors. Together, the Chairman, Vice Chairman, and the Chiefs of the four military services are responsible for setting strategic direction and broad military planning for both strategic and contingency situations (Joint Staff Officers Guide, 1991). Figure 3 illustrates the organizational structure of the department and can be referred to throughout the following discussion.

In addition to their responsibilities as Joint Chiefs of Staff, the four Chiefs of the services "wear another hat" while they supervise their respective services. The services are responsible for organizing, training and equipping forces so that they are capable of carrying out the assigned missions of the Unified and Specified (U&S) Commands. The U&S Commands are the "warfighters," responsible for carrying out national security objectives throughout the world by assuming operational control over the services' units during war. Each service and command has a headquarters component that exercises control over all of its functions, including the definition of mapping requirements.

Mapping requirements may include requests for new products required for development of weapon systems or the definition of area coverage requirements for certain products for

Department of Defense (DoD) Organization

Source: Joint Staff Officer's Guide, 1991

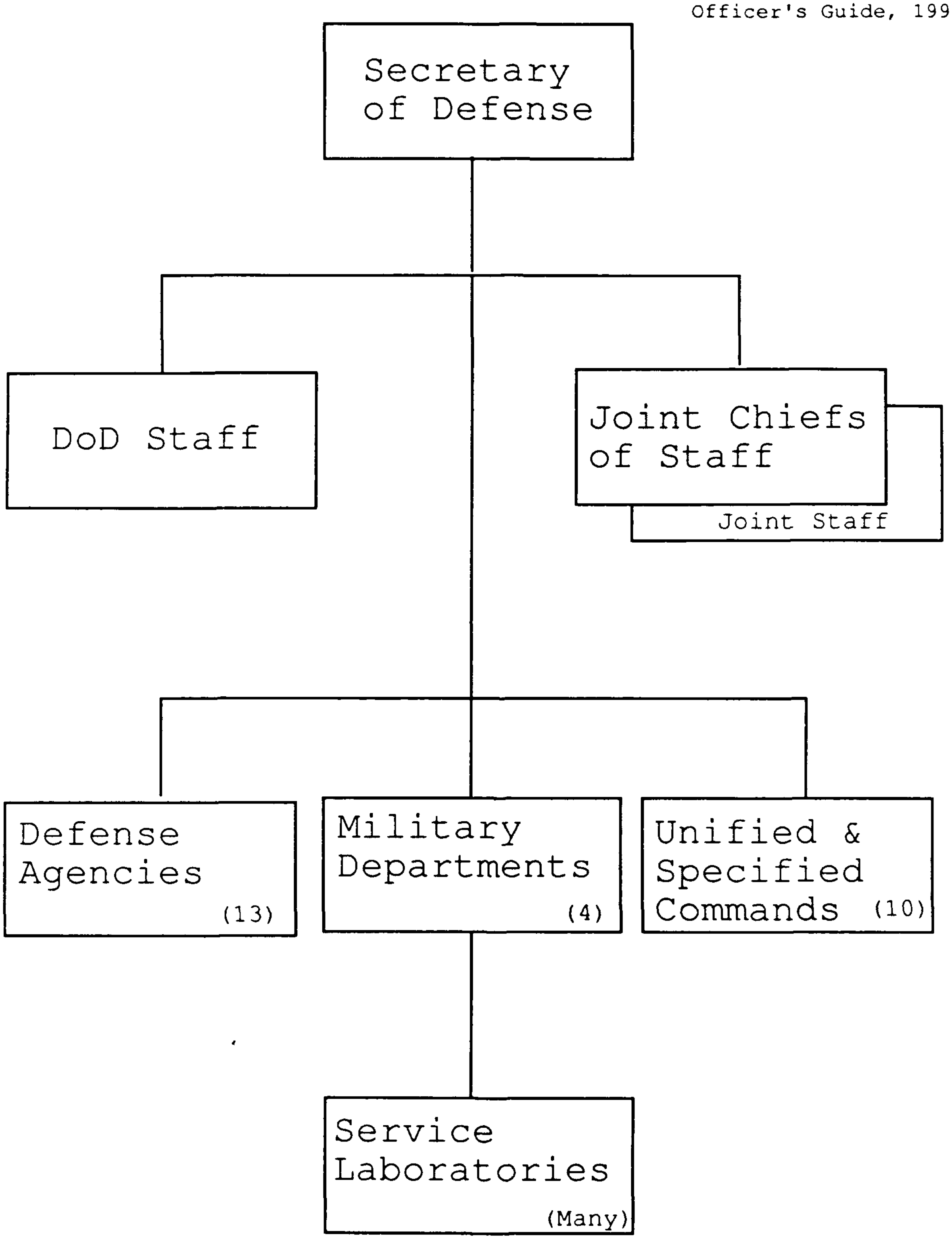

Figure 3

figure 3

operational purposes. Each service has a laboratory responsible for the planning and development of new mapping technology (in the Navy and Army's cases the laboratories focus solely on mapping technology while the Air Force laboratory that accomplishes this function has a broader mission). The labs are the primary submitters of new product requirements which must be forwarded to DMA through the service headquarters.

Unified commands are joint-service commands (two or more military services) responsible for certain areas of the world or certain functions. The Unified Commands responsible for specific areas in the world are: U.S. Pacific Command, U.S. Atlantic Command, U.S. European Command, U.S. Southern Command (responsible for Latin America), and U.S. Central Command (responsible for most of Africa and the Middle East, including Asia Minor). Unified Commands responsible for carrying out specific functions are: U.S. Transportation Command, U.S. Special Operations Command, and U.S. Space Command. Each of the Unified Commands consists of a small headquarters staff during peacetime. During war, Unified Commands take control of operational units provided by the services to carry out operational war plans. Specified Commands include Strategic Air Command (Air Force) and Forces Command (Army); each is responsible for broad continuing missions generic to each service (nuclear deterrence in the case of the Air Force). Specified Commands have large headquarters and control many units in the course of their continuing, day-to-day missions (The Joint Staff Officers Guide, 1991). The commands submit the largest block of requirements for area coverages due to their global operational commitments.

Defense Agencies are mostly civilian organizations, performing specific non-combat functions within the department which also require them to submit mapping requirements. They include:

Defense Advanced Research Projects Agency
Defense Communications Agency
Defense Contract Audit Agency
Defense Intelligence Agency
Defense Investigative Service
Defense Legal Services Agency
Defense Logistics Agency
Defense Mapping Agency
Defense Nuclear Agency
Defense Security Assistance Agency
National Security Agency
On-Site Inspection Agency
Strategic Defense Initiative Organization

Each agency interacts with the Joint Staff, Unified and Specified commands and the military services in differing ways. For instance, the Defense Intelligence Agency serves as the Joint Chiefs' staff intelligence element in addition to its duty to provide intelligence support information to the commands and services. The Defense Mapping Agency supports the entire department by responding to requirements levied by the commands, services, defense agencies, and others.

Interaction between Commands, Services, and DMA

It is important to remember that the military services are primarily responsible for submitting new mapping requirements for emerging weapon systems and tactics to DMA. The services use their service labs to refine their requirements, often taking new products from DMA and letting the labs run the tests and evaluations. In addition, the laboratories submit requirements for developing systems through the service headquarters to DMA.

Combat commanders in the Unified and Specified commands submit requirements to DMA for area coverage of the standard products DMA produces. Defense Agencies and other government entities also submit requirements to DMA but traditionally receive less attention since the combat commands and the services receive the lion's share of support due to the size of their requirements and the magnitude of the systems they employ (see Figure 4 for a representation of the operational relationships between DMA and its customers).

All of the requirements submitted to DMA are prioritized according to a scheme implemented by the Joint Chiefs of Staff. The exact nature of the decision criteria used to determine who gets top priority support remains classified but can be said to favor operational commitments of deployed military forces. The system is far from static and lower priorities frequently move up the ladder, including those of the smaller units and defense agencies. This movement may be at the direction of the Joint Staff or internally programmed by DMA.

Within this organizational context of mapping affairs, we will now look at the recent history of the new product planning and area requirements processes. Developments in these areas have greatly influenced the way in which DMA sees its own responsibilities and its role within DoD.

Defense Mapping Agency's Customer Support

In the dynamic world in which we live, DMA must constantly work to be responsive to the seemingly ever changing needs of the user community. New product planning takes place

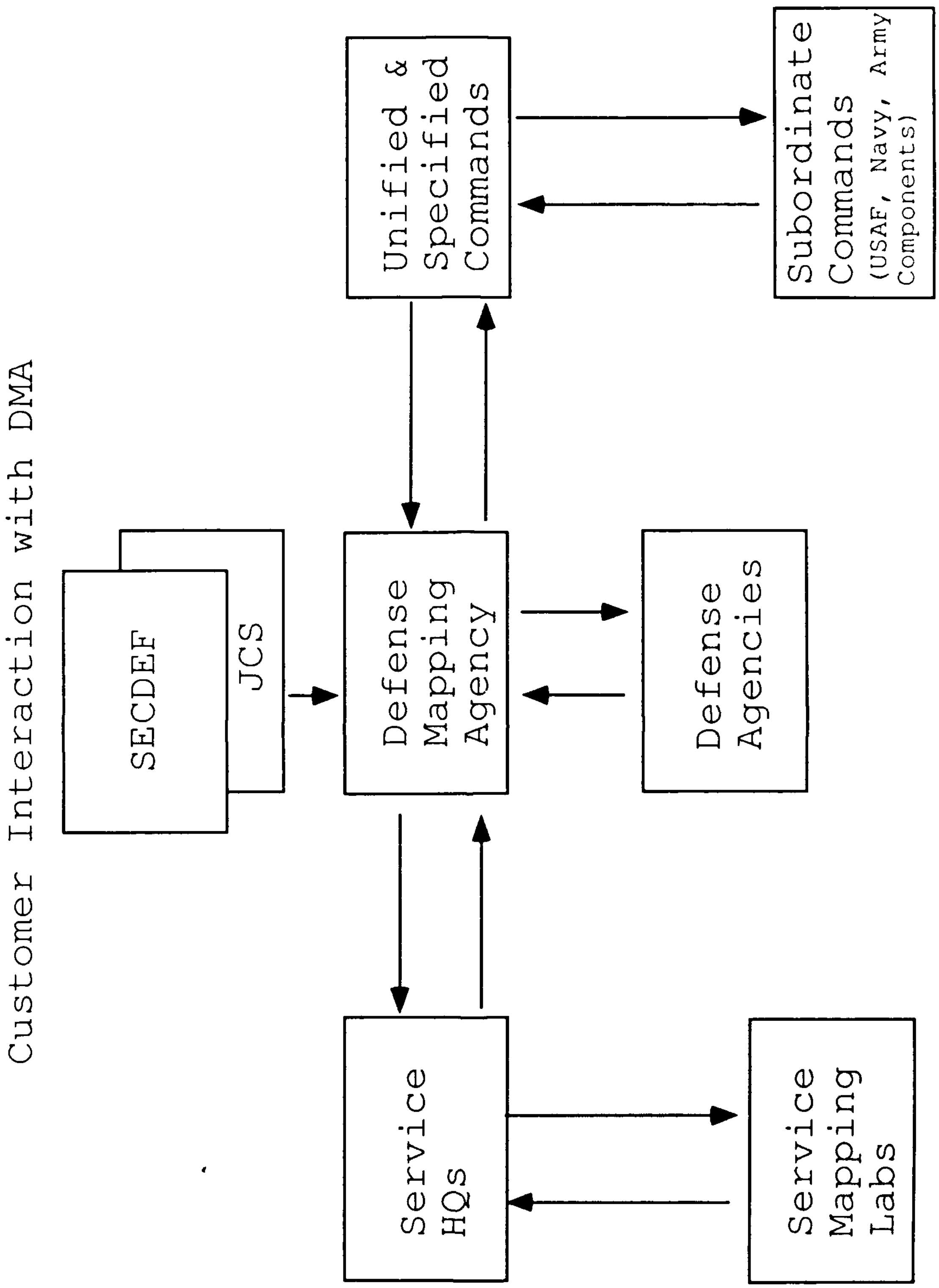
Customer Interaction with DMA
SECDEF
JCS
Defense Mapping Agency
Unified & Specified Commands
Subordinate Commands (USAF, Navy, Army Components)
Defense Agencies
Service HQs
Service Mapping Labs

Figure 4

as needed, and is very common as new weapon systems are developed which require digital mapping data. Military contingencies, real-world as well as exercises, often throw the orderly structure representing DMA's best efforts to plan new products and produce according to area requirements into chaos.

As a relatively small agency, DMA often suffers neglect from the designers and developers of weapon systems. Designers often fail to express requirements for new mapping or digital products, or submit them to DMA very late, in the development cycle. DMA can not easily uncover and track every weapon system development project in the department and must rely on the developer to determine mapping requirements. Military commanders also have had an historical tendency to keep DMA in the dark regarding certain requirements because of the need for security. Recent steps have helped to correct both of these situations but the agency still faces an uphill battle in making its case known.

The agency's efforts to win these battles has led to a new role for DMA, a role which was internally generated as a form of survival strategy. DMA now tries very hard to anticipate user needs by remaining in close contact with new weapon system developers and combat commanders. Because of the size and organization of the Department of Defense and the communication system in place, this is difficult at best. Other efforts to win this battle, such as the recent attempt to adopt digital mapping data standards to force developers to utilize existing DMA products, lacked any real direction for a number of years. The standards effort also suffered from a lack of real enforcement options and consequent neglect. All of these things together combined to spur DMA to adopt a new attitude and direction for its activities.

DMA's Traditional Role Versus Recent Needs to be More Proactive

In 1983, the United States undertook a military operation to invade the island of Grenada and rescue American college students from the perceived dangers of the political and social upheaval associated with a coup d'etat. This engagement marked the start of the change in DMA's role in the Department of Defense. Leading up to the invasion, DMA served as a giant map factory, churning out thousands of maps a year at an incredibly slow pace. Maps and digital data often took 18 months or more to produce while changing to crisis production often meant a complete halt to all extraneous production in favor of products supporting contingency operations. The planners of Operation URGENT FURY, as the Grenada invasion was known, decided to keep DMA out of the loop in the planning process and rely on the Army's minimal topographic assets for maps. This decision was based on the perception that DMA could not provide the maps in the required time frame without a massive production effort. Such an effort would have jeopardized security because of the vast numbers of people at DMA who would have had to have knowledge of the impending operation. Only when the operation was imminent did a request come to DMA for the standard set of combat maps and charts. The result was the now famous "British tourist map" that served as the Army's base map and was used by the invading forces until DMA's standard products arrived well after the fighting began.

This "tourist map" was actually a very good map produced by the United Kingdom's Ordnance Survey. However, Army mappers overlaid an arbitrary, Universal Transverse Mercator (UTM) -like, grid on the map to accommodate military operations such as artillery support. This map worked well until personnel confused the arbitrary grid with the UTM grid for the region. Matters were not helped when DMA rushed standard military maps to the area (with genuine UTM grids).

The resulting confusion, "friendly fire" incidents, and the like led to efforts to make DMA more responsive to real-world contingencies and to get the military commands to loosen operational security enough to alert DMA far enough in advance to allow the production of standard maps, charts, and digital data. Over the years, the processes for communicating the users' new product and area coverage requirements continued and slowly improved.

Throughout this metamorphosis, DMA strived to condense production time through internal measures and to reach out to the commands with proposals to improve communication and trust. However, other circumstances such as the need to adjust operating budgets throughout the government led to situations which impacted DMA's ability to satisfy its users.

Impact of Budget Cuts on New Product Planning

The usual approach to new product development at DMA has been via a top-down specification model. This approach requires a great deal of effort at the front end by both the developers and the users. Once specifications are written, the developer can proceed to produce the final product according to the blueprint. It is possible that the first users' test of the new product may be very near to final delivery, or at least not until after a great deal of time and money has been spent implementing the design. This approach is not unique to the Defense Mapping Agency; many Army, Air Force, and Navy laboratories also function in this manner. As a result, it is not unusual for projects to require long lead times, sometimes on the order of a decade for large projects. Under this procedure, DMA bore the costs associated with new product development unless an urgent, unprogrammed request required the transfer of funds from the customer's development account.

Reduced budgets in the middle 1980s forced certain decisions regarding the way in which DMA and the services interacted during new product planning. When cruise missiles were developed in the seventies, the developers built the missiles and specified the data needed to make them work. DMA paid for the development of products such as Digital Terrain Elevation Data and Terrain Contour Matching Matrices used by the missile for navigation and targeting. As the eighties wore on, budgets became increasingly smaller while technology allowed new and more advanced weapon systems to be built. To counter the Soviet Union's continued deployment of more and more advanced weapons, the United States military responded by developing new requirements for weapon systems and the associated mapping data needed to make them work. Eventually this led to a decision in a DoD document pertaining to DMA's budget known as PDM 85 (or Program Decision Memorandum, 1985). PDM 85 stated that services specifying the need for new mapping products for developing weapon systems must pay for the products (other conditions also applied such as cost thresholds, etc., but they are not relevant to this discussion).

It should not be surprising that under these conditions a number of requirements for new products suddenly disappeared. In addition, it has been asserted that other requirements for some digital data sets never materialized since no single service desired to pay all the costs of a product that every other service within the department could use. Weapon system developers decided to make do with transformations of standard DMA products or circumvented the system by directly contracting with civilian firms for the required products. In fact, DMA was put into the awkward position of trying to negotiate between elements of the user community in these matters. To this day, PDM 85 has not been enforced.

One consequence of the actions brought about by PDM 85 was that a frame of mind developed among many users who began to go to commercial vendors to acquire digital data. Contracting with vendors was perceived to be faster and easier than working with DMA. This led to a proliferation of data in a wide variety of formats and media and to interoperability problems between military commands.

To alleviate interoperability problems, DMA decided to formalize what had been "de facto standards" associated with the success of certain products. This type of "standard" product was only considered a standard because so many systems used the data and because there was a vast amount of data available. Digital Terrain Elevation Data (DTED), which was used by more than 100 systems (Digital Products Study, Summary Report, 1991) is a prime example of one of these "standard" products. The former "de facto standards" were processed by DMA through the Department of Defense office responsible for military specifications and standards and were formally converted to Military Standards (MILSTD). Weapon system developers were then required to use DMA data for specific applications; Digital Terrain Elevation Data became the MILSTD for all systems requiring digital elevation data. A standard for topologically structured data did not exist because DMA did not directly provide GIS users with much useable data in this area (although DTED is often used in GISs).

Confusion Among DoD Users of GIS

DMA's traditional focus on supporting the commands and services remained its primary goal during efforts to use a proactive approach to head off surprises in the new product and area coverage requirements processes of its biggest customers. Attempts to implement standards for the use of products, coupled with perceptions generated during an era of increasingly tighter budgets, led to a great deal of confusion when DoD elements began to implement Geographic Information Systems.

Intelligence agencies, which perform varied analyses of world events, were well suited for the adoption of GIS technology and were the first users of GISs within DOD. Because DMA lacked topologically structured data sets and paid little attention to the intelligence agencies' requirements in day-to-day operations, these first GIS users carried out their activities unilaterally. In addition, since their GIS activities were often conducted in highly classified programs, the intelligence agencies did not try very hard to move DMA into the GIS arena due to security concerns.

As more and more elements in DoD added GIS capabilities, including the commands and services, DMA tried to enforce digital data standards for its existing products, which failed to meet the users' needs. It soon became apparent that the agency needed to support GIS users with standards and topologically structured data. The Digital Chart of the World project was undertaken for these reasons.

CHAPTER 4

THE DIGITAL CHART OF THE WORLD CASE

The Defense Mapping Agency recognized a need to provide a topologically structured data set to the DoD community to "support the selective display, geographic, modelling, analytical, and predictive capabilities" (Danko, 1992) being introduced by the adoption of GIS technology. They believed that to encourage use of this database there must be a wealth of data developed according to a standard format. A global database like the DCW would be well suited for users who have applications in command, control, communications, and intelligence, mission planning, and global monitoring. In addition, DMA has stated that the international mapping community has long been interested in building a global database such as the DCW (Danko, 1992; Bickmore, 1988).

While these are worthy reasons for undertaking a project such as the DCW, it is clear that the original requirement for these standards and data sets originated from, and was defended from within, DMA. We will see that many users are in fact concerned about DMA's efforts to produce a product based upon needs sensed by the agency rather than expressed by the people DMA serves. In the following sections we will deal with these issues, but first we will look at the way in which DMA executed the project, given that they decided a need existed, and the response to their use of prototyping by the people involved in every aspect of the project.

Implementation of Prototyping

It is difficult to precisely state why DMA attempted to use prototyping in the DCW project. Prototyping in this case was probably intended to be used as a requirements analysis tool, in accord with recommendations in the software engineering literature. However, the beginning phases of the DCW project violated key premises of prototyping as a requirements analysis tool. In addition, it is important to note that DMA often uses the terms "prototyping" and "rapid prototyping" interchangeably throughout its documentation of the DCW project (see the Statement of Work (1988) and subsequent articles by Danko (1990 and 1992) for illustration). In fact, DMA's use of the term "rapid prototyping" has little in common with Connell and Shafer's methodology and is probably an adequate description only when one considers the length of the development effort and the impact the DMA-imposed completion date had on the prototyping process.

The Statement of Work issued by DMA to interested commercial contractors clearly laid out the reasons for the development of the DCW and the way in which it was to be accomplished. Prototype development was to be used to "aid in the development of standards and to insure completeness in compatibility, information content, and overall design" (SOW, 1988). The need to determine users' requirements for the product or the standards were not mentioned in this section; instead it states "[t]he prototypes will be distributed by (sic) DMA users for test and evaluation. The contractor shall use the results from this and other prototype data interactions to improve design" (SOW, 1988). This statement implies a rather mechanical process aimed at implementation activities. These initial statements are subsequently contradicted by assertions that "iterative" prototyping was used "to ensure that the final standards are user oriented and meet user requirements" (Danko, 1992). The latter assertion indicates prototyping was intended as a requirements analysis tool, but because the former was expressed in the Statement of Work, it probably more accurately reflects DMA's original thinking. This discrepancy is noteworthy because it is the first of many indications that user needs were not a primary concern in the selection of the development strategy. DMA's need to establish standards and support them with data was likely the primary driving force of the prototyping effort.

One needs only to examine the stated purpose of the Project Requirements Review (PRR) to determine whether user requirements were of the utmost importance. The PRR was the first meeting between DMA and the contractor and was held in the middle of November, 1989 to assure that the contractor understood all the details of the project requirements. Presentations at the PRR were supposed to include an "[i]nitial requirements matrix allocating DCW attributes and characteristics to [a] specific prototype version or revision" (SOW, 1988), indicating a preconceived notion of user needs. One may be surprised to find out that an assessment of user needs was not accomplished before this meeting. Instead, a User Needs Survey was circulated at the PRR and was completed by only seven participants. DMA obviously had a predetermined set of requirements for the project before both the PRR and the user survey were accomplished.

During initial research at DMA headquarters, the author was told that the contractor (ESRI) had insisted upon the initial user survey which was performed at the PRR in order to determine what the real requirements were for the DCW standard and product. One DMA interviewee stated the contractor persisted in this area because they never had worked on a project where a user needs survey hadn't been accomplished. The DMA speaker told the author he was surprised by the contractor's insistence and asserted that while the users really needed the DCW, "they just don't know it yet." Variations of this statement, that the users needed the DCW and similar data along with digital data standards oriented toward GIS users but "just haven't expressed a requirement," were repeated throughout the interviews conducted at DMA.

DCW Development History

Despite the untimeliness and limited scope of the assessment of user needs, the design process continued and was refined based upon input from representatives of the user community. The development of the standards and the DCW product can be traced through the construction of four prototypes, each of which was issued to an increasing number of review sites. Each prototype consisted of increasing quantities of data from a cross-section of DMA products (to ensure the standards would support the building of more data sets at different scales in the future). In each case, users were generally allowed 30 days, or less, to review the prototype before a design review meeting was conducted. An example of the instructions issued to the reviewers is contained in Appendix 4.

The DCW first prototype was a small data set which used standard ARC/INFO software to display a mockup of the DCW and was delivered to about 40 reviewers. The second prototype consisted of custom software and data from several cartographic products on magnetic media. This allowed more users to evaluate the database structure as well as the software provided which enabled the user to view the data. The third and fourth prototypes, which were on Compact Disks - Read Only Memory (CD-ROM), more closely resembled the intended final product based upon Operational Navigation Charts and were delivered to more than 70 reviewers.

An examination of the time line associated with the prototyping activity provides an important view of the entire development process. The issue dates of the prototypes together with the design review meeting dates are listed here in chronological order. These are graphically illustrated in Figure 5.

Table 2
Prototype Issue and Review Dates

Event	Date
Project Requirements Review and User Needs Survey	October 1989
Prototype 1 Release Date	December 1989
Design Concept Review	January 1990
Prototype 2 Release Date	April 1990
Preliminary Design Review	May 1990
Prototype 3 Release Date	July 1990
Project Detailed Design Review	August 1990
Prototype 4 Release Date	December 1990
Critical Design Review	January 1990
Interim Progress Review	July 1990

Further details about the development process will be highlighted through a review of key documents and augmented in a subsequent section by an analysis of the participant's responses to the DCW prototyping effort.

Execution of the Prototyping Process

Several documents supplied by the contractor provided insight into the development of the DCW database and associated standards. Each design review, except for the Project Design

Prototype Issue and Review Schedules

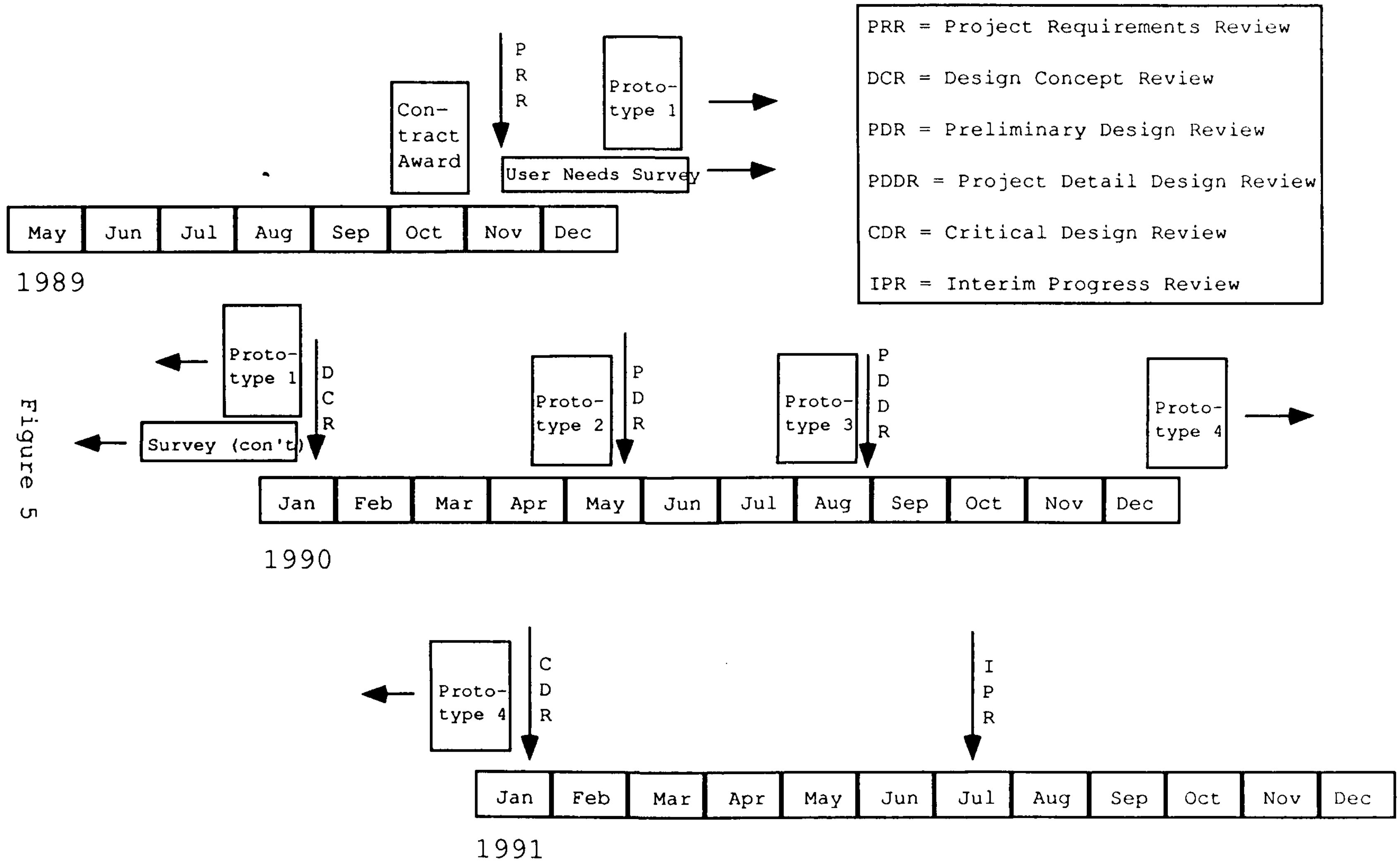

Figure 5

Review, was preceded by the delivery of a preliminary data package of information to the participants. These data packages included information about the next meeting, including a detailed agenda, and a summary of the last meeting and the activities that had taken place during the interceding period. Information about the Project Requirements Review was included in the Pre-Design Concept Review Data Package. Users who acted as reviewers of the prototypes were invited to each meeting along with developers, DMA personnel and their international cooperative partners, and subcontractors. In general, the Design Concept, Preliminary Design, Project Detailed Design, and Critical Design Reviews were intended to discuss the contractor's activities, the prototypes, and input from the users regarding their needs and evaluations.

As previously stated, the PRR was the first meeting between DMA and the contractor and was supposed to be held to insure that the contractor understood the project requirements. Although it is very clear that there were preconceived notions about the user requirements ESRI took advantage of this meeting to conduct the User Needs Survey to get first-hand knowledge of requirements directly from the intended users (the survey is attached as Appendix 5). Because of the unfortunate aspect of the timing of these activities, the first prototype was delivered at the end of December 1989, while the compiled results from the survey were not available until the middle of January (the compiled results of the User Needs Survey are in Appendix 6). Consequently, the only direct input from prospective DCW users was not utilized in building the first prototype (Pre-DCR Data Package, 1990).

The first prototype (40 copies) was delivered during the end-of-the-year holiday period in 1989, one month before the Design Concept Review (DCR) was scheduled. This Prototype consisted of a small section of one ONC, and a small patch of a British Admiralty chart. The reviewers were provided with ARC/INFO software to perform the evaluation of the first prototype (Danko, 1990). It is important to note that reviewers were only provided with approximately 30 days to perform their functions despite problems associated with the holidays, mailing time related to delivery of the prototype, and dispatch of their comments back to the contractor. The DCR, held at the end of January, 1991, focused on the contractor's conceptual design of the DCW and utilized user input and the results from the User Needs Survey to begin discussion and development of the second prototype (Pre-DCR Data Package, 1990).

Prototype 2 was produced between the DCR and Preliminary Design Review and required 12 weeks for its creation. This prototype was issued near the end of April, 1990 and used original code, written in the C language, to implement the new DCW data structure. The data utilized consisted of the two previous charts and also included two National Ocean Service charts and a section of a 1:50,000 topographic map (Danko, 1990). Work on the Vector Product Standards made significant strides; the conceptual design was completed and included database content definition, layer definition, and CD-ROM design. This prototype was delivered to more than 50 reviewers and provided the first complete view of the product and its contents (Pre-PDR Data Package, 1990). The PDR was held at the end of May, 1990 and was used to discuss product content, the vector standards, and design issues such as tiling and indexing of prototype 2.

Prototype 3, the first to be delivered in CD-ROM form according to the new standard format, the Vector Product Format, was issued in early August, 1990. This prototype consisted of several ONCs, hydrographic charts, and one Jet Navigation Chart. It was the first to provide the standards, software, and data in one product to the evaluation team (Danko, 1990). The time period available for review of this prototype was considerably less than the 30 days allowed for both of the previous prototypes. User comments and production design were presented at the Project Detailed Design Review held at the end of August 1990 (Pre-PDDR Data Package, 1990).

The fourth and last prototype was delivered at the end of December, 1990, just one month before the Critical Design Review (the CDR was originally scheduled for December but was delayed until the middle of January, 1991). Prototype 4 was designed to test both the data structures and the production process using four ONCs from western Europe (Danko, 1990). The purpose of the CDR was to provide the Government assurance that the contractor's design was adequate to allow database production to begin. Final standards, software, and production designs were presented. During this period, significant upheaval in the development was caused by the contractor's need to support other DMA activities during Operation DESERT SHIELD/STORM. The impact of this support will be discussed in more detail later in this paper. The Interim Progress Review was designed to provide the Government with information regarding production status and was held during the middle of July, 1991. Schedules and status changes were discussed and a prototype for Digital Terrain Data was released. This latter prototype was initiated by DMA as a result of the progress demonstrated at the DCW Critical Design Review as well as DMA's satisfaction with the prototyping process and the Vector Product Standards. DMA stated that the DCW "method of rapid prototyping worked very well. Engineering ideas were quickly tested; the designs that didn't work were quickly discovered and discarded" (Danko, 1990).

Changing Justification for Prototyping

This last statement reflects how DMA was more interested in the traditional implementation activities so often the focus of software engineering methodologies. It is another indication that satisfaction of the users' requirements was not the goal of prototyping in the DCW development project. Unfortunately, this statement further clouds our effort to determine DMA's rationale for the use of prototyping in the DCW development project. Further insight into the prototyping process will be provided by an examination of the participant's views regarding the DCW effort.

Participants' Responses to Prototyping

For purposes of this study, there were three primary participants in the project; the project sponsor (DMA), the developer (ESRI), and potential users (military commands, services, and DoD agencies). Participants from each category were contacted during visits to three sites. Their roles in this project will be examined in the following section along with their reactions to the process as a whole.

Project Sponsor

Interviews at the project sponsor level were held with six individuals, including the contracting officer technical representative as well as personnel involved in the program through work in research and engineering and user requirements definition. Some consistent themes ran throughout the interviews. Nearly everyone agreed DMA is changing to accommodate real-world situations and the jump to GIS technology. How they think DMA should undertake this controversial and complicated task is less clear.

Every interviewee admitted that DMA was anticipating requirements in the DCW case. The power of the intelligence community is rising within the DoD and DMA sees a strong need to provide them with more support. The intelligence community is involved in every important national contingency, from military operations to the continuing battle over narcotics trafficking. Their role in these situations and their efforts to modernize how they accomplish their tasks through the use of GIS technology has earned them a great deal of respect. Most DMA personnel believe that the intelligence agencies see DMA as unresponsive to their needs due to DMA's pre-occupation with supporting the military commands and services. DMA sees an operational need to support the intelligence community with products to help accomplish their increasingly important and highly visible mission. DMA also sees the intelligence community as a stepping stone to the military community in the commands and services. Military commands still tend to depend on developing specific systems and requiring specific products for those systems rather than taking a broader perspective of digital geographic requirements. DMA's effort to support GIS activities in the intelligence community and to aid the successful adaptation of GIS technology in DoD was intended to help change the military's mind set.

DMA was determined to execute the DCW project for largely self-serving reasons. Because GIS users were mishandling the exploitation of a new technology in the department through individual arrangements with GIS contractors for systems and data, DMA believed a digital standard for GIS data was needed. In DMA's view, the availability of large standardized data sets was also necessary to influence the users into utilizing the new GIS databases. DMA also believed prototyping was the most appropriate methodology for use in this development project for several conflicting reasons.

One interviewee at DMA Headquarters stated that prototyping in the DCW project was required because DMA had a potentially wide user base for GIS-related products and prototyping offered a way to involve many users at one time in a development project. DMA recognized that the DCW project was a break from the traditional method of developing digital mapping products and the intended user of this product was not a single entity. Another interviewee, who worked directly on the DCW project, stated that prototyping was used because it could "shave development time" and the standards and database were needed immediately. These differing perspectives account for much of the confusion reflected in the Statement of Work and other early documents.

Because the DCW project appears to have generated a beneficial product, that is the product standards and the database, a strongly positive perception of prototyping has developed within DMA. In addition, the availability of prototype products to support Operation DESERT STORM coincided nicely with DMA's efforts to become more proactive and anticipate their customer's requirements for products. Intelligence agencies used DCW as a background source at several briefings for the highest levels of government during Operation DESERT STORM. DCW-like products (1:1,000,000, 1:250,000, and larger scale digital products) were also deployed in limited quantities in the Kuwaiti Theater of Operations. One interviewee stated that many senior DMA managers were impressed by the prototyping process for this reason alone.

DMA's perception of the success of this project has led to another development effort based upon the "Digital Products Study" (1990). An outgrowth of this study advocated the use of the Vector Product Standards developed along with DCW to build a group of digital vector products at varying scales (1:250,000, 1:50,000, and larger). This project, called GEOMAP, is not oriented toward any specific system which requires the data, nor is there any written, formal statement of requirements from any users. It is simply an attempt : 'he agency to become user oriented, support the rapid introduction of GIS into DoD, and convince the user community that DMA is ready to produce the data they need to accomplish their missions.

Developer

Interviews at the developer level were primarily with the project manager and several others involved with production. The ESRI project manager communicated a wealth of information concerning the initial design efforts by the contractor as well as a summary of up-to-the-minute activities. As one might expect, the contractor was more familiar with the nature of prototyping and had a better comprehension of what the design process entailed. They were very concerned with the development of the standard and the production problems encountered in the normal course of such a large project.

Early discussions with the project manager by telephone elicited some interesting perspectives on the DCW project. The lack of a formal user needs assessment by the sponsor was promptly recognized and rectified by the conduct of a limited formal survey. The project manager admitted that the user needs inherited from DMA at the start of the project were "not what we had hoped for." However, he also stated that his understanding of the real reason for the project and the prototyping effort was to establish a GIS-oriented digital data standard as soon as possible. This would allow DMA to control the introduction of GISs and related data sets into the Department of Defense. Certainly the commercial value of being associated with the DCW project in this regard was not lost on the contractor.

The interview at the DCW contractor's site provided information on their design methodology. ESRI had long realized the value of putting a concrete example of their proposed system into the hands of the entity who would be making the decision on awarding contracts for GIS systems and related products. However, these examples were demonstrations of their system's capability rather than a true prototype.

In the database design methodology used by this company, the flow of effort followed a simple path:

1. Determine and define user needs.
2. Perform conceptual design of the database.
3. Perform physical design of the database. This may include the use of prototypes.
4. Implement the design.

The project manager believed that the need to carry out the project quickly, within a two year time frame, impacted their ability to perform but did not hinder the prototyping itself. The same number of prototypes could easily be produced in the allotted time frame, in his view, but the number of meetings to discuss their efforts could have been reduced.

It is interesting to note that the development team was able to devise the Vector Product Standards in the very short span of two years. Because the sponsor (DMA) contracted for this as a product, a small team was able to bring many resources to bear upon problems usually encountered in standards development. This is in direct contrast to most other standards development efforts which are initiated as joint efforts between several large organizations. The federal Spatial Data Transfer Standard and international projects such as the North Atlantic Treaty Organization's Digital Geographic Information Exchange Standards are more typical of the latter type of standards development project. For instance, a federal committee worked for five and one half years before producing a draft proposed standard for digital cartographic data in 1987 (National Committee for Digital Cartographic Data Standards, 1987).

Another critical factor that helped speed the VPS effort was that the standards were user oriented rather than representing exchange standards for transfer of data between cartographic producers such as DMA, NOAA, and USGS. A user oriented standard is one in which all parties could make use of the data "as is", without having to transform the data at either end of the exchange process. In the view of ESRI, implementation of the Vector Product Standards by production of a database according to the new standards was a wise move by the DMA.

Users

At the start of the Digital Chart of the World project, only seven users were involved. All filled out the User Needs Survey (see the last page of Appendix 6 for a list of the users and their organizations who responded to the survey). This group grew during the prototyping process to total more than 70, cutting across a broad spectrum within the Department of Defense. It was possible to conduct on-site interviews with three users participating in the DCW development. Consequently, the United States Army Engineer Topographic Laboratory, represented the service labs who participated, the United States Air Force Intelligence Support Agency which serves as the headquarters component that deals with mapping, charting and geodetic matters for the Air Force and represented the services, and the Defense Intelligence Agency Military Geography Division represented GIS users in this study. Several other shorter interviews were conducted by telephone.

Comments by this group varied widely and were representative of the different individual perspectives of each interviewee. The service headquarters element had a global perspective on mapping and charting support in DoD. However, they still complained about the way in which this project may have detracted from DMA's primary mission of producing products for specific requirements, although they realized the importance of the standards development. The service laboratory was more interested in their own products and complained about the rapid pace of the prototyping effort. The GIS users welcomed any effort to produce a product which they may use but remained skeptical about the way in which the developer was obtaining and responding to input from the field.

Several of the users were concerned that some of their comments on the different prototypes had not been acted upon and were seemingly ignored. They also felt that since there was no formal requirement for the product, and the specifications were being derived in concert with its development, that the contractor had a license to discard user suggestions that were appropriate but might prove difficult to implement. All of the users involved in the prototyping process agreed that the pace of the project placed undo stress on them. Most mapping offices within the commands, services, and other agencies are staffed by very few people, it is common to have between one to four people in such an operation. In the case of service labs, the degree of resources which can be allocated to a project such as this, which had not been previously coordinated within one of the budget documents, is also extremely limited. In the present case the Army laboratory could only afford to assign two people to the review process and of these, one was only minimally involved.

All of the interviewees recognized the need for standards as well as the need for DMA to be proactive while at the same time striving to maintain the level of support required by currently fielded systems. The Air Force service reviewer notably called for an end to system- and time-specific development of digital mapping data in favor of a broader approach which would be capable of satisfying a wide range of user needs with a single, integrated product such as a master database.

Participants' Perspectives as a Building Block

Clearly the three main groups of participants each held a unique perspective on the implementation and utility of prototyping in the DCW case. Our task is to derive a set of findings and recommendations from the experiences of these groups to evaluate the use of prototyping in the design of Geographic Information Systems and related components.

CHAPTER 5

LESSONS LEARNED FROM THE DIGITAL CHART OF THE WORLD PROJECT

Several findings emerge from this study that may have a significant impact upon the way in which prototyping operations can be incorporated in the GIS design process. It is important to document these findings and provide recommendations so that future use of this development technique can be made effective.

Prototyping in the DCW Project

Prototyping as implemented in the DCW project was intended to assist DMA in accomplishing its goal of developing standards for vector products and a digital spatial database that could be stocked and distributed to users. However, because of the conflicting reasons for initiating the project (as stated in the documentation and in interviews with DMA employees), the DCW development project can not serve as a good example of the use of prototyping as a requirements gathering and analysis tool in GIS design. DMA's preconceived agenda for the establishment of vector data standards, the contradictory reasons for using prototyping in this case, and the neglect in developing user requirements in the early stages of the development effort violated several rules for the effective use of prototyping in system design.

The first problem arose out of the generation of a product (the DCW database) which no one explicitly required while quickly trying to develop a digital data standard for topologically structured data. As the project wore on, DMA admitted that the standard was the most important part of the project and that the database was generated to support the adoption of the standard. How this admission may have colored the initial content of the product and the conventions incorporated in the digital data standard is unclear. Since most users recognized the need for topologically structured data, they participated in the definition of requirements for the database even though few had firm plans to use it. This led to some bad feelings between DMA and its customers which could have been alleviated by early communication of the real purpose of the project. If the real reasons for the development project were admitted by DMA up front, the debate over whether prototyping was used as a requirements analysis tool or as an implementation tool may be moot, despite any of DMA's assertions affirming one use over another.

Since the development schedule was rushed by DMA's own deadlines and the User Needs Survey was accomplished only after the prototyping process began, the users faced enormous difficulties in evaluating and responding to the prototypes. Communication between developer, sponsor, and user was inefficient and several misperceptions of the DCW developed and were allowed to remain in place. The rapid nature of the DMA-imposed schedule may have also influenced the downstream structure of the database as well as the standard because some user inputs were submitted too late for incorporation into the next prototype.

These shortcomings emphasize three lessons to be learned from this case study which will lead to recommendations for the future use of prototyping in GIS design.

DCW Development Project Findings

Three crucial violations of the use of prototyping as a requirements analysis tool are illustrated in the Digital Chart of the World development:

1. The initial impetus for undertaking this design project and the reasons for the use of prototyping were not well defined or linked to an assessment of the users' requirements.

2. Communication between DMA, ESRI, and the users was hampered by the rapid pace of the project and the lack of an efficient mechanism for effective, two-way exchange of information.

3. Documentation focused on the activities surrounding the issue and review of the prototypes and was contradictory and incomplete at the start of the project.

User Requirements

There was either an unwillingness or an inability on the part of the developer to provide the author with any documentation other than the SOW which may have given the initial impetus behind DMA's DCW project. The fact that DMA was anticipating future user needs was well explained and justified during interviews at DMA; however, it was not clear in the documentation whether the requirement for the DCW product or the standards came first. It seems likely that the agency felt the need to develop user-oriented digital data standards first to control the proliferation of GIS in DoD, and decided the best way to carry out this project and test the standards would be to build the 1:1,000,000 scale DCW. A formal survey of customers making use of GIS and their needs for data and digital standards before the initiation of the development project could have provided significantly more focus for the effort.

Because DMA believed a wealth of data was needed to enforce the standards, the ONC was chosen for the basis of the global digital database. The ONC series could provide world wide coverage and provide large amounts of data to help ensure the standard was followed. However, the elementary need to have a wealth of data available does not alleviate the developer's responsibility to ensure the customers' were willing to use the data to be produced. A more formal definition of user needs prior to project startup may have shown that there was no need for the DCW product itself, but that the users were willing to support the development because they understood the need for standards (and would be applying the standards to later production of other databases). This type of survey (a survey was performed during the "Digital Products Study" (1990), half way through the DCW project) might have provided good support for DCW effort. If the users were unclear about their needs in the survey, it could have been used as justification for development of a digital data standard and may have helped substantiate the decision to proceed with prototyping of a topologically structured database.

In this case, prototyping was used either to ensure that the standard and the database met the requirements as defined by the users or to cut development time. We may never know the real reason due to conflicting statements by DMA. A strong indication that the use of prototyping was more an effort to quickly develop a product that was acceptable to the user, as opposed to one defined by them, can be seen in the fact that the User Needs Survey was completed by only seven users and that the results of the survey were not even ready before the first prototype was completed.

The first prototype was delivered in December 1989 and took six weeks to produce (Pre-Preliminary Design Review Data Package, 1990). The User Needs Survey was dated

November 1989 (see Appendix 5), and the Pre-Design Concept Review Data Package (dated 09 January 1990) stated that a sub-contractor was "assembling a synthesized view of user requirements." This indicates that the first prototype was developed with little or no user input.

Because DMA and the contractor had a preconceived idea of what the prototypes ought to look like before any of the users were involved, questions in the User Needs Survey were framed from a point of view which implied that the development of the DCW was a foregone conclusion. Instead of asking what the user needed, they were asked how they would make use of the DCW (another question stated: "[p]lease indicate the information classes from DCW which you will use" indicating that a pre-selected set of thematic layers existed). Still, prototyping did work to modestly increase user involvement in requirements refinement activities since the user group grew from the original seven to eventually number more than 70 reviewers.

Communication

Perhaps the biggest issue identified during this study was that the interaction between DMA, ESRI, and the users was less than perfect. Since DMA is a separate agency with its own charter and its customers are outside of its direct control, the need exists for a fluid and early interaction between the sponsor/developer team and the users. During project planning, designers must properly inform users as to what to expect in a development project and the rationale for those actions. They must also focus on users' requirements from the start by interacting with the users at the earliest opportunity. This would also have allowed users outside of DMA to adequately plan for their participation in the development project.

DMA initiated this project rather suddenly, taking many of the users by surprise. DMA felt it was responding to perceived needs, subsequently justified by the number of customers who expressed an interest in using topologically structured data, but not necessarily the DCW database. Had conditions been different, DMA might have been better served by lobbying for one or more users to submit a formal requirement for DCW-like digital data and a digital vector data standard. This would have appeased many of the feelings among the services and the commands that DMA had sharply moved away from its primary role of providing support to the operational users through the development of an undesired product.

Better communication could also have alleviated the stigma of the DCW as a research and development project producing a spatial database that might be put on the shelf due to lack of interest. Several DMA employees admitted that customers will eventually use the DCW database, but that use at first will be limited to intelligence agencies and others adopting GIS technology. DMA strongly feels that many users will employ other digital products built according to the VPS as a result of the Digital Products Study and the GEOMAP initiative, despite the fact that no formal requirements have been expressed.

Some of the users may have been confused about the required level of their participation in this "R&D" project because they did not know it was being planned, nor did they understand that the goal of developing the digital data standard had paramount importance. Notably no user involvement was funded or programmed before the project was initiated. Every user outside of DMA paid their own way to the meetings and provided the necessary hardware at their sites to perform the reviews of the prototypes. Better communication between the sponsor/developer and the users could help cultivate a relationship where prototyping can be more effectively carried out.

Because the users were not part of the organization performing the design and development work, there was also a tendency for them to lose track of the status of the comments and input they provided to the development team due to inadequate two-way communication. Many users stated that they provided what they thought were substantive comments only to see them ignored when the next prototype was issued. The developer stated that many times comments were late and therefore were not used in the design of the next prototype. Clearly communicating this situation directly to the users through some sort of formal response mechanism would allow better flow of data on subsequent iterations. The user could then make more timely submissions, reiterate points he felt were important but not picked up by the developer, and so on.

Along with requests to participate in the review of prototypes, a more detailed plan must be included in any prototype project to unequivocally inform the user of what he is to expect and do. The first letter in the Pre-Design Concept Review Data Package contained very little information in this regard. Several of those invited to the Design Concept Review did not receive the first prototype but were invited because they had expressed an interest in participating or were contacted about participating. They were presumably informed about their role in some way.

Finally the time constraints placed on this project were the subject of discussion at every interview. There is no documented reason for the constraints as imposed by DMA (at least none were provided) and the users were not consulted prior to the establishment of the schedule. Several interviewees stated that the time constraint worked against their individual efforts but was favorable to the overall conclusion of the project. The time periods between development of prototypes and the period when comments are due should accommodate the reviewers as much as possible but should also be set within written criteria, with sound reasons provided as a background for these decisions.

Documentation

Because the sponsors, designers, and developers were most concerned with the functionality of the system and in meeting deadlines, there was a decided neglect with respect to documenting what had taken place. As soon as work was done on one prototype, work began on the next phase without going back to adequately document activities. Clearly, complete design documents were required and at a minimum should have included Data Flow Diagrams, Entity-Relationship Diagrams, and perhaps Control Flow Diagrams to substantiate the user requirements for the software and the conceptual model of the database. This presumes the flow of the design process was organized in accord with modern software engineering techniques such as structured analysis (e.g. the Marble-Wilcox model).

A Prototyping Model for GIS Design

A methodology which relies upon prototyping as a major tool for the definition of user requirements, documentation of design activities, and smooth communication of system functions and goals could be implemented by adapting portions of the design methodologies reviewed in this paper. As Marble and Wilcox (1991) state, optional pilot studies can assist in determining user requirements but are not often used because they are expensive (especially when modelling an entire system), and require "expository selection of GIS software." Prototyping could be used in place of pilot studies to perform user requirements analysis in the implementation of small systems, where Marble and Wilcox's cost concerns could be lessened. The development or selection of GIS databases and applications, which are more limited in scope than system implementation, offer even better opportunities to use prototyping to benefit GIS design.

Connell and Shafer's recommendations for using CASE tools in conjunction with a relational database management system (RDBMS) to demonstrate proposed solutions to user requirements could be adapted to GIS database and application design. For example, in an application development, items from a data set could be retrieved using the RDBMS and displayed in the sample screens and menus (generated using CASE tools) to model the operation of the program. The same would hold true for the development of a GIS database since the project would also likely include software to allow the user to view data prior to his development of tools or systems to use the data. A tool for illustrating the spatial dimension of queries in a graphic environment needs to be developed and tied to this methodology for use in GIS design.

The iterative process illustrated in Figure 6 could be used as a specific procedure to begin the development of a GIS database or application design project. Activities in step 1 entail preliminary contact with the user, a first cut at the user needs assessment, and the planning (with the user) of project schedules and deliverables. Next the organizational implications of the proposed project must be evaluated and incorporated into a listing of user requirements (step 2). Finally, fourth-generation tools are used to model and create working skeletons of the proposed application or database (step 3). Iterative prototypes are constructed until the user is satisfied that the requirements analysis is complete (activities in step 2 may need to be revisited and refined). From this point, more traditional methodologies could be employed to perform application specification or database design activities.

A Prototyping Model for GIS Design

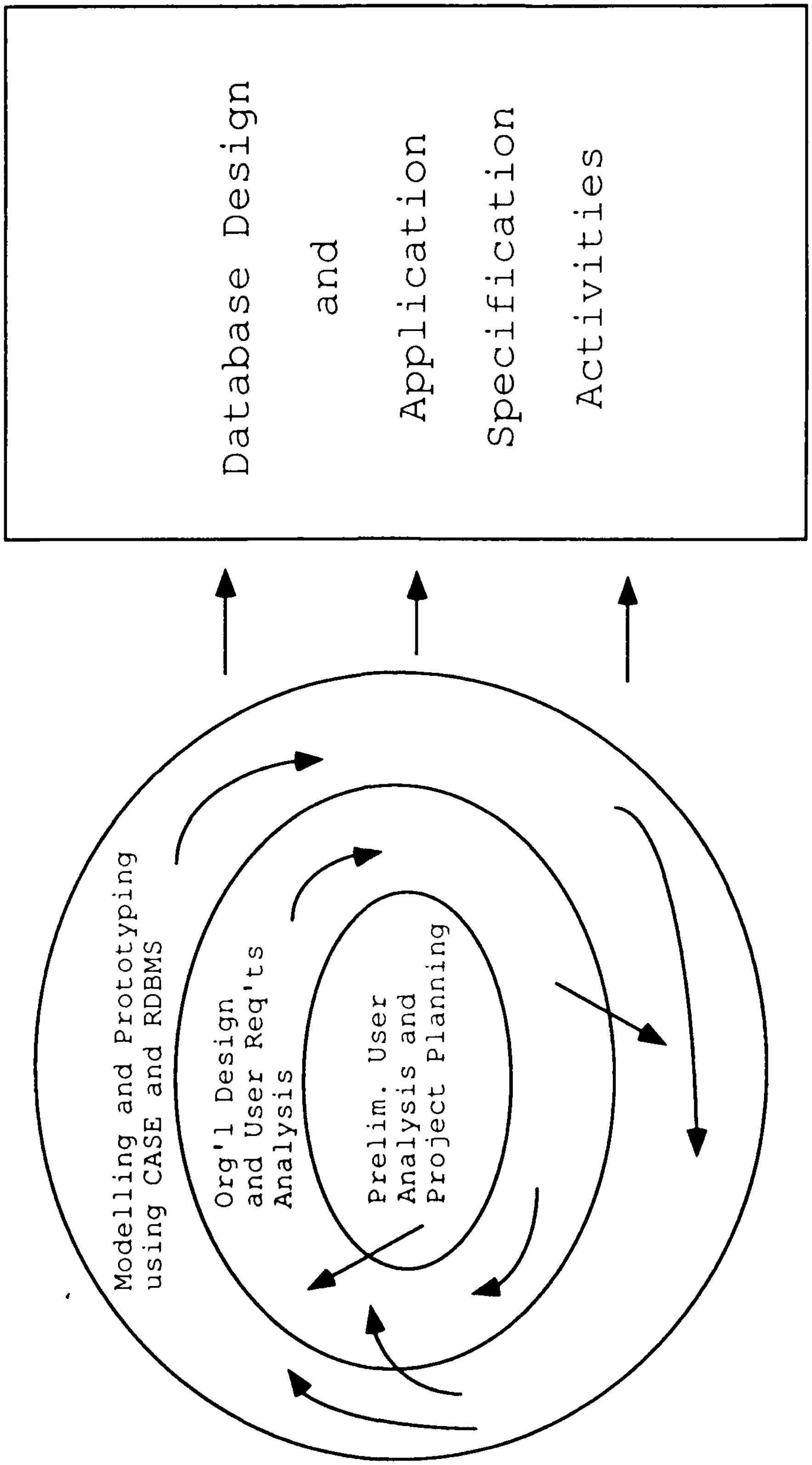

Figure 6

The proposed methodology outlined above would maximize the advantages of prototyping; at the same time, care must be taken to minimize the disadvantages. Effective communication between developers and users would lead to an improved user interface and lessen the customer's false expectations from the prototypes. Products of the CASE tool (DFDs, ERDs, and CFGs, along with the proposed spatial display screens) would significantly aid final specification of the database or application while also providing a degree of flexibility to the design process.

The proposal to use this procedure is only an initial attempt to take advantage of the potential that prototyping offers to GIS design through the enhancement of user requirements analysis. Prototyping in GIS database or application design needs to be tested and refined using appropriate procedures and constraints before it is widely accepted. The results of the DCW design process, though not a good example of the prototyping process, illustrate that it is a viable alternative to using the top-down specification model in all GIS design projects. Increasing the interaction between designers and users is critical to successful implementation of Geographic Information Systems.

CHAPTER 6

CONCLUSIONS

This study of the Digital Chart of the World development project looked at the use of prototyping in the GIS design process by examining the adoption of a rapidly growing technology (GIS) in the unique arena of the Department of Defense. Unfortunately, this study illustrated that prototyping has yet to make a transition from a procedure primarily benefitting physical implementation activities to one which may significantly aid Geographic Information System design during the definition and refinement of user requirements. The way in which prototyping was utilized during DCW user requirements analysis, the poor communication between DMA, ESRI, and users, and the lack of effective documentation in this case all violated several key assumptions of prototyping.

The DCW development clearly demonstrated a fragmented approach to user requirements analysis but indicates that prototyping can aid in the definition of user needs. To its credit, prototyping delivered the DCW product directly to the user at various incremental levels of detail and allowed the user to test the adequacy of the database and make recommendations for changes to the product and the digital data standard. However, this required a structure for quick and efficient interaction between the user and the developer/designer team, a structure which does not exist within the DoD Mapping, Charting and Geodetic community. Communication throughout the project, but especially at the start, is important to the success of any prototype process, especially where the participants are from different organizations requiring formal interactions.

Recommendations

Several recommendations may be suggested for organizations wishing to utilize prototyping in GIS design activities. Each recommendation stems from a finding in the DCW case study but has universal relevance to other such design efforts, whether on a large scale such as DMA's attempt to interact with its customers in the GIS arena or one firm's endeavor to provide its client with a beneficial product.

1. The initial impetus for undertaking a design project, and the reasons for the use of prototyping in that project, must be well defined and linked to the need to iteratively develop and refine the users' requirements.

2. Effective communication between developer, designer, and users is critical to unqualified success in a prototyping project.

3. Documentation of the entire process, not just the middle and end where more tangible activities occur, is crucial.

Prototyping can most effectively be used as a requirements analysis tool in GIS design if its capabilities to increase interaction with the users and to iteratively define and satisfy user requirements are recognized as essential at the start of a project. Once the decision to use prototyping for these reasons has been made, project managers must ensure that the users remain the focus of the development effort and ensure the proper environment exists to maximize two-way communication between parties. Users should be consulted before project planning is begun so that they are aware of their responsibilities and can become familiar with the feedback process. The developer would be wise to establish a specific mechanism for the communication of their responses to the users' feedback on the prototypes. All of this needs to be clearly spelled-out in advance.

Future Work

Prototyping needs to be tried as it was intended to be implemented by Connell and Shafer, and others, before it is judged fully capable of being incorporated into GIS design methodologies. Coupling prototyping with structured design methods and using it to determine and refine user requirements from the outset of a project would appear to offer the most potential. At this point, it would appear best suited for use in small-scale projects where close control can be exerted over the users and designers alike.

A test should be developed where two versions of the same GIS component (perhaps an application or a database) will be designed using two approaches; one group could use a traditional top-down specification model like the Marble-Wilcox model while another group could develop a product using a structured prototyping process. The test should be structured similarly to one reported by Boehm, et al. (1984), but must provide quantitative results pertaining to measures of user satisfaction with the two products and user evaluations of the requirements analysis activities. The outcome from this type of study could better lead one to decide whether traditional GIS design methodologies should be altered to specifically include a place for prototyping. It may also lead to a conclusion as to whether prototyping may be the preferred method for designing databases or applications in GIS development projects.

Conclusion

While the Digital Chart of the World development proved to be a poor example of the use of prototyping as a requirements analysis tool, it did illustrate that prototyping appears to offer significant potential for adaptation to the GIS design process. It is likely that with continued assessment and refinement, prototyping can play a role in GIS design, similar to other software engineering techniques.

APPENDIX 1

INTERVIEW PLAN

INTERVIEW PLAN

Objective:

To determine the effects of prototyping on the Geographic Information System database design process by studying the Defense Mapping Agency's (DMA) Digital Chart of the World (DCW).

Likely Effects:

Beneficial
- Increased user involvement in the development effort (feedback)
- Well defined user requirement
- Working models aid definition of user requirement
- Users can articulate what they don't want better than what they need the system to do, especially when they have a model to work with
- Better allocation of production resources resulting from prototypes
- Users may want to be more involved in prototyping other products

Disadvantageous
- Too much effort needed from overworked user during evaluation (time)
- Management restrictions on user participation (travel money, time)
- Misunderstanding that the prototype tested may not be the system delivered
- Users may want to be more involved in prototyping other products

Topics to Cover:

1. Position and responsibilities
2. Level/type of involvement with DMA
3. Level/type of involvement in evaluation of DCW prototypes
4. Impacts of prototyping
5. Evaluation of DCW project

Lead Statement:

"Mr. Smith, as you know, I am a graduate student studying the impact of rapid prototyping on the development of Geographic Information Systems and databases. Today I'd like to take the next hour or so to review with you your position, your interaction with DMA, and how you view the development of the DCW."

Lead Questions:

Topic 1. "Let's begin with your position and your major responsibilities."
Topic 2. "How do you participate in DMA product development?"
Topic 3. "I'd be interested in your role in the DCW evaluation project."
Topic 4. "How do you view the impact of rapid prototyping in the DCW project?"
Topic 5. "Let's summarize by discussing your views on rapid prototyping and the results of the project."

Follow Up Questions:

Topic 1.
- How long in present job
- Background and training

Topic 2.
- Can you break down the percentage of your job spent interacting with DMA
- How would you classify your interactions (operational, research, etc.)

Topic 3.
- How did you get involved in the DCW project
- How much time could you devote to the evaluation of the prototypes
- Tell me about the priority you assigned the DCW project

Topic 4.
- What are some of the impacts from prototyping on the product
- What are some of the impacts from prototyping on you and your organization

Topic 5.
- How well do you think user requirements were met
- What are your plans for using the DCW

APPENDIX 2

LIST OF INTERVIEWS

LIST OF INTERVIEWS

Kenneth Brunjes, Defense Intelligence Agency, Military Geography Division.

Irvin Buck, Defense Mapping Agency Headquarters, Acting Assistant Deputy Director, Plans and Requirements Directorate.

David M. Danko, Defense Mapping Agency Systems Center, Digital Chart of the World Contracting Officer Technical Representative.

Louis Fatale, U.S. Army Engineer Topographic Laboratories, Digital Concepts Analysis Center.

Lieutenant Colonel Paul G. Foley, U.S. Army, Defense Mapping Agency Headquarters, Plans and Requirements Directorate, Land Combat Division.

Glen Hill, Environmental Systems Research Institute, Digital Chart of the World Production Manager.

Rosanne T. Hynes, Defense Mapping Agency Systems Center, Research and Engineering Office.

Dean Karsok, Environmental Systems Research Institute, Digital Chart of the World Project.

Duane Niemeyer, Environmental Systems Research Institute, Digital Chart of the World Project Manager.

Christinia Pappas-Moir, Defense Mapping Agency Systems Center, Research and Engineering Office.

Juan Perez, U.S. Army Engineer Topographic Laboratories, Digital Concepts Analysis Center.

Neil Sunderland, U.S. Air Force Intelligence Support Agency, Mapping, Charting and Geodesy Division.

APPENDIX 3

SUMMARY OF THE
DIGITAL CHART OF THE WORLD,
FINAL MILITARY STANDARD,
VECTOR PRODUCT STANDARD

4. GENERAL REQUIREMENTS

4.1 General. Vector product format (VPF) is a generic geographic data model designed to be used with any digital geographic data in vector format that can be represented using nodes, edges, and faces. VPF is based upon the georelational model, combinatorial topology, and set theory.

4.2 VPF characteristics. VPF is designed to provide flexibility in encoding, directly accessing, and modeling digital geographic databases for a variety of applications on different computer systems. VPF characteristics are as follows:

a. Sheetless database support. VPF is designed to support a sheetless database by providing logically continuous topological relationships even when the database is physically partitioned into tiles. VPF structures support the query and retrieval of data that extends across tile boundaries.

b. Neutral format. VPF has a neutral product format that is used in combination with individual product specifications. VPF is topologically structured and supports various levels of topology, from simple cartographic vectors to polygon coverages with full two-dimensional cell topology.

c. Attribute support. VPF uses relational tables for attribute handling. Such tables support both simple and complex feature types.

d. Data dictionary. VPF contains a self-defining data dictionary and lookup tables that provide a schema for user understanding of features and their attributes.

e. Text and metadata support. Text information may be either attributes of features or "free floating" cartographic primitives. VPF is compatible with the use of all written languages, including accented characters and diacritical marks. In addition to basic cartographic information, VPF supports a variety of metadata files for carrying supportive information concerning all or part of the database.

f. Index file support. Any index files necessary to enhance database retrieval performance are also utilized within VPF. These can include spatial, thematic, disk location, tile, and gazetteer indices.

g. Direct use. VPF allows application software to read data directly from storage media without prior conversion to a working format. VPF uses tables and indices that permit direct access by spatial location and thematic content.

h. Flexible, general-purpose schema. VPF can represent digital geographic data in vector format by providing flexibility in the modeling of any of data organization, from fully layered to completely integrated. VPF supports two-dimensional and three-dimensional coordinates, multiple scales, and the creation of multiple products.

i. Data quality. VPF includes standards for data quality reporting and representation. It provides multiple methods for the representation of the spatial and aspatial aspects of data quality.

j. Feature definitions. VPF organizes features and thematic attributes to ensure logical consistency and completeness.

4.3 Relationship between VPF and specific products. The definition of data content shall be established in product specifications. VPF establishes a standard data model and organization, providing a consistent interface to data content. The product specification determines the precise contents of feature tables and their relationships. VPF can also accommodate additional tables that are not required by VPF itself. Figure 1 illustrates the relationship between VPF and specific products.

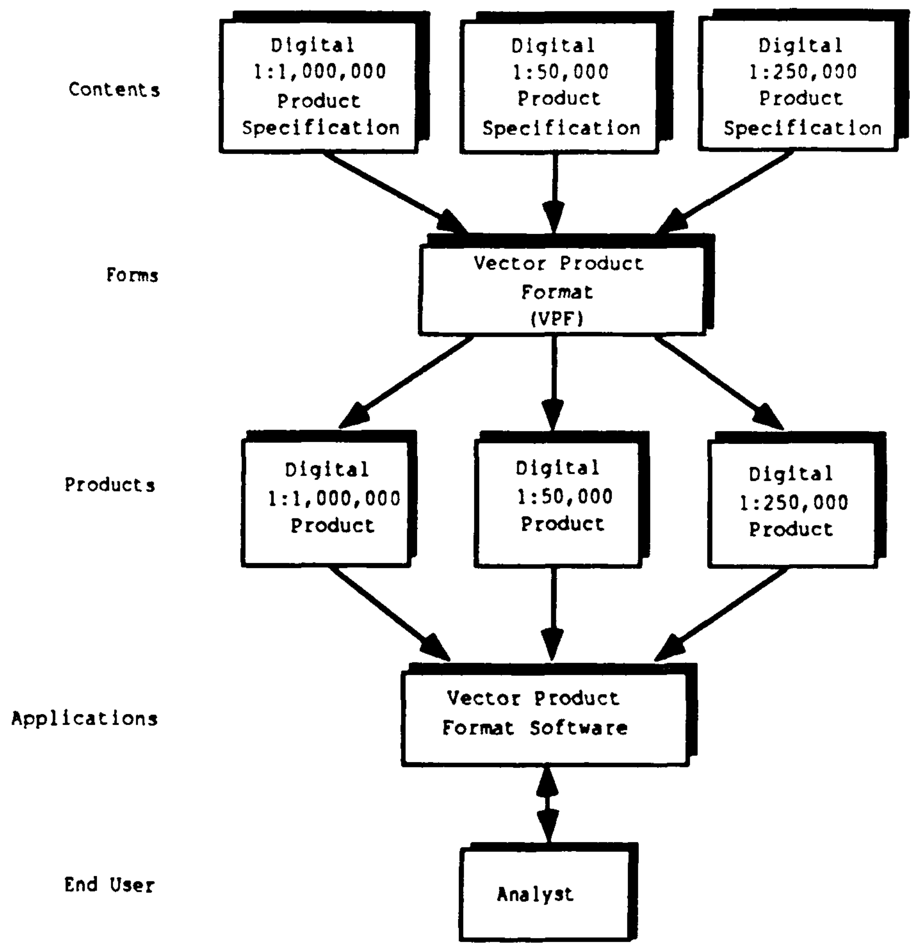

FIGURE 1. Relationship between VPF and specific products.

4.4 VPF hierarchy. A VPF database can be viewed as a five-level hierarchy of definitions (figure 2). This document explains VPF as a collection of the bottom four of these levels. The top level, which contains the product specification, is used to tailor VPF to create the required product.

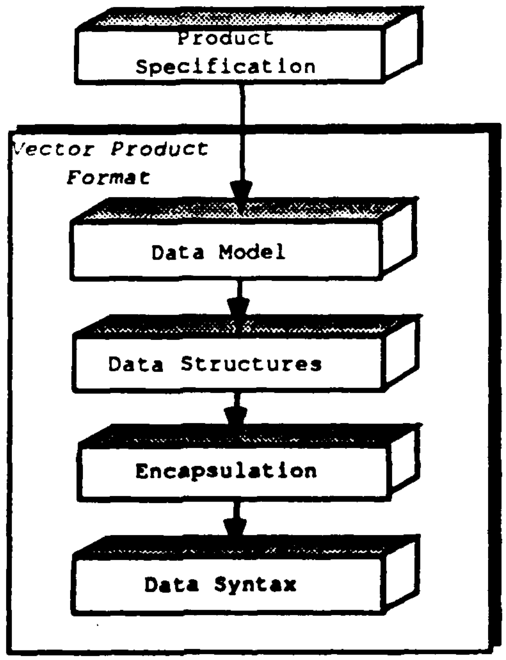

FIGURE 2. Vector product format structure.

The document has been organized to begin with the conceptual components and introduce more technical details in later sections. Section 5.2 defines the objects that are used in a database within the VPF data model. The data structures (section 5.3) define the mandatory implementation details in order to manipulate VPF data. This section fully details the concepts expressed in the data model section. Encapsulation is defined in section 5.4, where the data structure fields are identified. The data syntax described in section 5.5 represents the set of rules that governs the contents of the fields.

APPENDIX 4

EXAMPLE OF PROTOTYPE
EVALUATION INSTRUCTIONS

PROTOTYPE 4 EVALUATION INSTRUCTIONS

To conduct the evaluation, you will need the following items:

- A PC with Prototype 4 software loaded and running
- A CD-ROM drive with the proper Prototype 4 CD-ROM disc loaded
- A printed copy of all the charts used in this prototype:
  - ONC E-1
  - ONC F-1
  - ONC G-1
  - ONC G-2
- Plots depicting the data available in the Prototype 4 database. The plots will consists of halves of the ONC sheets. Half sheets of the ONCs were plotted in order for the plots to be represented at compilation scale (1:1,000,000) and projection. The plot of F-1 displayS the eastern half of the sheet, while the plots of G-1 and G-2 will display the western halves. The plot of the E-1 sheet is centered on the United Kingdom.
- The Prototype 4 Evaluation Form

Before you begin the evaluation, we suggest that you examine the plots and printed maps to establish a mental context for the geographic areas captured for Prototype 4.

The hard copy plots have beenprovided to allow you to determine whether the chart contents have been accurately and completely captured. Feel free to make notes on the plots as you evaluate the prototype; the plots serve as a reference to information within the database. After the CDR, you may want to retain the plots for use within your agencies.

The plots and their corresponding source charts have consistent scales and projections, so they may be overlaid on a light table for comparison purposes. Note that since the default display is generally projected on the screen by using a different projection, the shape of map features on the display and the plots will be different.

We suggest that you conduct an extensive evaluation of Prototype 4. The results of this evaluation will be the last to be incorporated into the DCW product.

Emphasis of .Prototype 4 Evaluation

The intent of these instructions is to focus your attention on those aspects of Prototype 4 which are new to the design of the DCW. The issues that have been identified represent additions and modifications that have been implemented in the DCW design since the release of Prototype 3. As most of these changes were the direct result of participant responses to previous prototypes, it is hoped that this focused approach to the Prototype 4 evaluation will sustain the progress we are making toward the development of the DCW product.

Evaluators may, of course, comment on any aspect of the prototype. However, we wish to encourage you to focus on identifying specific problems in the performance or content of the prototype. As this is a prototype development with demonstration software, problems in the implementation of the DCW design are certain to exist, and we greatly appreciate your assistance in identifying them.

Prototype Evaluation Issues

1. DCW Elevation Data. Prototype 4 introduces a new approach to the representation of elevation data. While the point and line coverages within the hypsography layer remain largely the same, the content of the polygon coverage has been revised. The polygon coverage for the hypsography layer in this prototype contains six elevation zones. As discussed at the PDDR, zones captured for this prototype were selected because they reflect important distinctions with respect to several natural and cultural factors. These factors include: vegetation patterns, agricultural uses, population distribution, equipment performance, and human health and comfort. Please examine the elevation data contained in the Hypsography and Hypsography Supplemental layers and comment on the following issues:

a. Are the zones contained in the hypsography polygon coverage able to provide utility as a tool for GIS applications?
b. Does the software allow the user to query contour data and shade contour intervals?
c. Does the polygon shading functions for contour zones execute properly?

2. Thematic Layers. Prototype 4 contains four thematic layers that were not available in previous prototypes: Vegetation, Landmarks, Transportation Structure, and Drainage Supplemental. These layers contain features that have been added to the DCW design since the last prototype. For Prototype 4, the contents of these layers are presented for **ONC Sheet F-01** only.

The Vegetation layer contains those areas labeled as "vegetation" or "clearing" on ONC sheets. The Landmarks layer contains a variety of point and polygonal features that have been captured on ONC sheets because of their visual prominence. The Transportation Structure layer contains a variety of transportation features that have been added to the DCW design to supplement the Road and Railroad layers. Finally, the Drainage Supplemental layer contains those small lakes and small inland water islands that fell below the minimum polygon size established for the DCW.

For a complete listing of the features contained in these thematic layers, please refer to the Draft DCW Product Specification. The design intent in capturing these layers was to complement the content of the DCW database without compromising its integrity. Please review the contents of these thematic layers with this in mind and comment on the following issues:

a. Do the features contained in these layers provide a valuable addition to the DCW database?
b. Does the organization of these layers in DCW design satisfy the requirements of your organization?

3. Software Functionality. Prototype 4 represents the final functionality of the DCW software. The focus of future modifications to this software will be internal engineering and performance enhancement. There have been a number of refinements and additions to the software functionality since the last prototype. Many of the comments received from participants concerning Prototype 3 software have been incorporated into this final software design.

Presented below is a partial list of the functions that have been added to the DCW software design since the last prototype:

• Zoom - Users will now be able to zoom in and out of the DCW database. The zoom capability may also be used to move from the DCW Browse map, which is the first data set visible to the user, to the more detailed DCW data set and vice versa.

• Help - Users now have access to a Help option. Help is available at both the main and pull-down menu levels. To access the Help windows, hold down the right button on the mouse or the F1 key.

• Generated Graphics - Users may now generate two types of graphics: (1) a latitude/longitude grid and (2) a scale bar.

• Status Windows - This software contains status windows that notify the user when software operations (e.g. drawing, initializing) are being performed.

• Selection by Pointing, Latitude/Longitude, or Placename - Users may now select a viewing area by pointing at any geographic location on the Browse map. They may also establish their viewing area by entering latitude/longitude positions or place names.

• Text Reports - Users may now produce three types of text reports. The Feature Location List and the Area Content Summary contain attribute information for selected features within a specific study area. The Feature Location List provides a report of the location of these attributes, while the Area Content Summary provides a report of their type and count. The IFACC correspondence report contains a comparison table of the DCW and IFACC coding schemes.

• Spatial Query - By pointing to a geographic location on the screen, users can identify the attribute characteristics of displayed features.

• Postscript interface - Users can now generate a Postscript plot file of the selected features. Access to this function is via the Hardcopy option under the Graphics menu.

Please examine the functionality of Prototype 4 software and comment on its new capabilities as listed above.

4. Symbology. Prototype 4 introduces several changes to DCW symbology. As with Prototype 3, this prototype includes a full default symbol set, which can be altered, completely replaced, or added to by the DCW users. Other advances have also been made in the areas of text and feature symbology.

The overall objective in developing the symbology for the DCW has been to design symbology that helps reduce clutter. One of the principal changes in the symbology since Prototype 3 has had as its objective the reduction of "text clutter." In Prototype 4, text is scaled directly in proportion to the source ONC text. The size of the text is related to the zoom factor selected by the user. Text is always displayed regardless of the display scale, but, to avoid the clutter problem at small scales, text will appear as a row of pixels. As the user operates the zoom function to increase the display scale, the size of the text increases proportionally. Text becomes increasingly legible with each successive zoom.

The user may also alter the color used for the text. Providing this functionality was essential to allow the user a free choice of color for areas; if only default colors were available for text, a user wishing to display areas and text simultaneously would have to avoid the default text colors.

Several additions have been made to the feature symbology set. Prototype 4 contains a digital version of almost all of the point symbols from the ONC source. Some of these symbols will need to be redesigned for the final product, but all are included for your evalutation.

Primarily because of the limits of screen resolution, line symbology remains less than ideal. The ability to display different line patterns is limited because of the substantial degree of clutter that results. However, the quality of "dot" and "dash" line patterns, which are now software generated, has been substantially improved for this prototype. The selection of line color and thickness will provide the most valuable tool for the user to optimize line symbology.

Perhaps the most important development in Prototype 4 feature symbology is the new approach to area fill. Area symbology in Prototype 4 makes exclusive use of the "pixel mixing" technique that was presented at the Project Detail Design Review (PDDR). The user can select the various color fills through the Change Symbology menu by indicating the desired colors and designating which of the four pixels that color should fill. Color fill is intended to replace cross hatching and other bold pattern fills, which have been eliminated from the symbology design. The decision to avoid area fills that use cross hatching or other pattern techniques reflectes our view that patterning adds substantial clutter to the screen while adding very little to the readability of the map.

Please examine the symbol set presented with this prototype and comment on the following issues:

a. Does the available symbol set meet user requirements?
b. Does the Change Symbology menu selection adequately support the user's capability to design symbology?
c. Do the changes in text and feature symbology improve the display of DCW data?

5. Browse Map. For Prototype 4, a Browse map has been introduced into the DCW design. It replaces the index map provided with the previous prototype. The Browse map has been designed to serve four main functions: (1) to provide a base map for the DCW start-up screen; (2) to provide a user-defined index base map for the DCW; (3) to provide a base map for the display of metadata; and (4) to provide a bounding geographic area context to support zoom-outs. In operating the Browse map, users should be able to:

- Select a specific area of the DCW to examine in greater detail
- Manipulate the zoom function to move from the Browse map data set into the DCW data set and back out again
- Retrieve metadata (e.g., compilation dates, data volumes, and data availability) from the DCW data set.

Please examine the capabilities of the Browse map and comment on the following issue:

a. Does the Browse map provide an effective tool for the selection of, and movement between, specific study areas?
b. Please provide recommendations for additional meta-data that you may require?

6. Data Accuracy. For Prototype 4, a new rule has been adopted for the representation of small polygonal features. In previous prototypes, polygonal features with a circumference of less than 0.12 inch were eliminated from the polygon layers of the database. These features were eliminated because they fell below the minimum polygon size that could be resolved during the automation process.

In response to participant concerns, a new procedure has been adopted. For **ONC Sheet F-1**, small polygonal features that were eliminated from Prototype 3 because they could not be captured as polygons have been converted to point features and retained. To examine these point features, select a study area within the border of sheet F-1 and display the point coverages from the Drainage, Political/Oceans, and Hypsography Supplemental layers. Please review the representation of these features and comment on the following issue:

a. Do these features provide a valuable addition to the DCW database?
b. Does the organization of these layers in the DCW design satisfy the requirements of your organization?

7. Edgematching. Prototype 4 represented the first opportunity to employ and examine edgematching procedures for the DCW because it is the first prototype to contain adjacent ONC sheets. In developing edgematching procedures, three issues were identified:

1. Locational Issues. Certain features, primarily linear features, do not match across module boundaries. When mismatches occur, the linear features from the less accurate module are matched to those in the more accurate module.

2. Connectivity Issues. There is a certain amount of overlap between adjacent ONC sheets. Because the sheets have different compilation dates, the features within the overlap area will not match. Generally, only the recent sheet will be used as a data source.

3. Attribute Code Issues. Because of different compilation dates, attribute codes may change across module boundaries. When this occurs with linear features, a pseudonode is placed on the module boundary and the linear features are coded separately. When this occurs with polygonal features, the polygon is split along the module border and the faces, as well as their composite edges, are coded separately.

The results of the procedures adopted to address these issues can be examined by focusing on the border areas between ONC sheets. For example, the border between sheets G-1 and G-2 is useful for examining linear edgematching within the hypsography and road layers. Where edgematching has been performed on the roads layer, the resulting linear feature will be coded as a that which was compiled from an adjacent source. The border between sheets F-1 and G-1 is useful for examining polygonal features in the hypsography and drainage layers. Because it is possible to display the latitude/longitude grid on the screen, it should be easy to identify the border between ONC sheets. Please examine those areas of the prototype which are subject to edgematching and comment on the following issue:

a. Do the edgematching procedures adopted for the DCW appear to maintain the continuity of features across ONC sheet boundaries?
b. Are the ONC data coded correctly near sheet boundaries?

8. Tiling Structure. Prototype 4 represents the first implementation of a tiling scheme for the DCW. While the tiling scheme is largely invisible to the user, it is of tremendous interest because of its role in database management and its impact upon performance.

Prototype 4 contains two tiling schemes for evaluation: a 5° by 5° data partition and a 3° by 3° data partition. The area of these tiles may be viewed on screen while features are being drawn. Features are drawn to the screen within the extent of each tile. For a graphic representation of these tiling schemes, please refer to Figures 7 and 8 in the Draft DCW Product Specification.

As discussed in the Final Tile Design Study (CDRL B001), ESRI is recommending that a fixed tiling scheme be adopted for the DCW. However, a decision concerning the size of the tiles is being withheld until we conduct a thorough examination of the performance of Prototype 4. As a result of our initial examination of Prototype 4, we are considering the use of larger tiles (e.g., 7° by 7° or 10° by 10°). This, we feel, might substantially reduce the number of data files and improve performance. While the choice of tile size will, of course, be driven by all of the factors identified in the Tile Design Study, we welcome your comments on the following issue:

a. Do the tile sizes available in this prototype adequately meet your needs for the display of data or does your work lend itself toward the use of larger or smaller tiles?

9. DCW Packaging. The DCW packaging design has undergone considerable revision since Prototype 3. The design presented with this prototype is much closer to the final design which will accompany the completed DCW product.

The CD-ROM pamphlet is very similar in content to the pamphlet distributed with Prototype 3 but differs noticeably in appearance. The packaging effort has focused on designing a recognizable "look" for the DCW which would be functional for all elements of the DCW product. In response to participant comments, the design has evolved significantly since Prototype 3.

For this design, the front cover of the pamphlet displays the Robinson, rather than an azimuthal, world map projection. The back cover of the pamphlet now displays the geographic area covered by the database on the CD-ROM rather than a list of participants. Because the previous pamphlet was too thick, this pamphlet was reformatted to display print on both sides.

The primary change in the content of the pamphlet is the inclusion of an index to the final DCW product. The disc label maintains consistency with the pamphlet by employing the Robinson projection. The design of the label is geared toward easy recognition of the DCW.

Please review the contents of the CD-ROM pamphlet and the other elements of the DCW packaging and comment on the following issues:

a. Does the CD-ROM pamphlet provide an informative and accurate introduction to the DCW product?
b. Is the design of the packaging visually appealing?

10. DCW Interactive Performance. As you examine Prototype 4, you may become frustrated with its interactive performance response. Those of you who have attended the DCW design reviews are aware of the performance constraints that the VPF standard, the CD-ROM media, and the minimum hardware configuration have placed on interactive speed. Since the development of the data standard has been our primary goal, our design approach has been to first develop a data structure that supports direct use on either the CD-ROM media or on hard disks of larger machines. This has now been accomplished. Our secondary goal is to make the DCW product on the CD-ROM media a well-performing database on small machines. This goal needs further work. We feel that performance can be improved by modifications to the software and by increasing the tile size to reduce the number of files. Our analysis of the performance of Prototype 4 is still in its initial stages. A set of solutions to improve performance will be presented at the CDR in January. Please feel free to comment on this issue.

11. Miscellaneous Issues. Please use this space to list any other software, database or symbolization problems that you encounter. Since this is the final prototype of the DCW design phase, these comments will be valuable in our efforts to create a product that is responsive to the needs of its users. However, it is important, at this later design stage, to concentrate on identifying the problems you encounter rather than on recommending new DCW capabilities. Most of the new functions that have been recommended in the past have been incorporated into Prototype 4, and we are confident that the DCW has now focused on your specific requirements.

Evaluation of DCW Product Specification

The Draft Product Specification for Prototype 4 defines the DCW implementation of the Vector Product Format and the content of the DCW database. It is intended to provide a detailed description of the design, data format, and content of the DCW database. Please examine the Draft DCW Product Specification (CDRL B002) and comment on the following issues:

a. Does the Product Specification adequately reflect the content of the Prototype 4 database?

b. Is the Product Specification in compliance with the content and format requirements for a military product specification?

c. Does the Product Specification adequately describe the technical specifications of the DCW database?

Please note that your comments on the Product Specification should be mailed under separate cover to the address below. Comments must be delivered to DMA by December 28, 1990, to be considered.

Ms. Pat Hudson
DCW Assistant COTR
DMASC/WG
3200 South 2nd Street—Bldg. 36
St. Louis, Missouri 63118-3399

APPENDIX 5

USER NEEDS SURVEY

USER NEEDS ASSESSMENT

Questions for consideration

1. What is the hardware and software environment in which you will be using the DCW?

2. Are you using existing small-scale (i.e., 1:500,000 or smaller) digital geographic data?

3. What kinds of existing digital data are being used? Please include level of detail indicators: DFAD, Level II, etc.

4. What are your current applications of these data?

5. Are your applications in an automated cartography-based system or in a GIS?

6. What, if any, problems or limitations have you experienced with your current digital data?

7. What types of applications of digital geographic data are you planning in the future?

8. Are there capabilities that you would like to see in new digital geographic databases?

9. What, if any, current uses of ONC data do you currently have within your organization?

10. Identify the potential projects (current or future) which are potential users of the DCW (or DCW-like) databases.

- Project names and stage of development.

- Project scope (1 system?, 5?, 10?, 20?, . . . 2,000?).

- Dates when data are needed.

- Area of coverage required.

- Hardware (storage media available, processor capacity, display characteristics, and other elements relevant to the use of the databases).

- Software and/or standards to be used which impact the application of the database (e.g., all data in the system are to be in WGS 84, 2851 GTDB data structure).

11. Describe the intended use of the DCW database. For example, are the data to be used for:

- Terrain visualization (background displays? other?)

- Route planning (visibility analysis? avoidance of populated areas? . . .)

- Reconnaissance planning (sensor appropriateness?)

- Ground location determination

- Navigation (background? visual correlation? . . .)

- Etc.

12. Please indicate the information classes from DCW which you will use:

a. Land cover
b. Hydrography
c. Roads
d. Contours
e. Relief and city tints
f. Special use airspaces
g. Projection grids
h. Culture symbols
i. International boundaries
j. Text
k. Aeronautical/vertical obstructions

13. Which of these will be used separately?

14. What combinations of these classes will be used together?

15. What preferences do you have for DCW data structure? Should the information categories be:

    1. Individually accessible?
    2. Grouped together?
    3. Some combination of the two (specify)?

16. What transformations will be required before your system will use DCW (reformatting, thinning . . .)?

17. ONCs have contour information. Will your use of DCW require elevation data? If so, will these contours be adequate?

18. If the contours are not adequate, what kind of elevation data is required? Format? Resolution level? Accuracy?

19. What use will be made of elevation data in your system?

20. What transformations will be performed in order to use elevation data?

21. If you have identified a requirement for elevation data other than contours, are the contours also necessary? If so, must the contour and the other elevation data match (and in what way)?

22. What types of output products do you plan to generate and what are their graphic display characteristics?

23. Is there anything else that you will need from the DCW to make effective use of it in your work?

24. How will the DCW fit into your organizational plans for geographic data?

25. What recommendations do you have regarding DCW?

26. What point(s) of contact in your organization should we use for further questions?

27. Do you have any other questions or comments?

APPENDIX 6

NOTES ON DCW USER NEEDS

Table of Contents

Notes on DCW User Needs   January 12, 1990   Brian G. Holmes

1 Introduction.

The following is information for the User Needs Assessment report for the Digital Chart of the World (DCW). At present, the source of this information is the seven responses gained from a questionnaire circulated at PRR. Of these responses, five were from offices of the United States government, and only two were from foreign offices. This presents a problem in gaining an accurate assessment of the foreign user need.

For example, one of the foreign respondents uses Intergraph workstations with the TIGRIS package, and the other was not able to identify the environment under which DCW would be used. Only one other respondent mentions Intergraph systems, and even then it is one of five other possible systems.

2 Design and Analysis Information.

The following subsections contain information that has been derived from the questionnaire responses. This information is of most assistance in the DCW design effort.

2.1 Computer Environment.

Three general computer environments represent the majority of possible systems under which the DCW will be used.

PC system (286) operating in a DOS environment

VAX system operating in a VMS or UNIX environment

SUN system operating in a UNIX environment

The respondents also mention higher level PC systems (386) operating in UNIX, and Intergraph workstations. Mention was also made of HP9000, IBM mainframe, and Apollo computer systems.

While most respondents did not list the software packages under which they operate, a few did mention use and experimentation with ARC/INFO, GRASS, and in-house systems. TIGRIS, MOSS, System 9, MapGrafix, PACE, and SPANS were also listed.

Most respondents indicated that they use both GIS and automated cartography-based software. The use of in-house software and software currently under development was also discussed in several of the responses.

2.2 Current Use of Small Scale Data.

Most respondents stated that they currently used small scale data of one kind or another, or that they planned to use the DCW as a small scale source. Sources mentioned included ONC, TPC, WDB II, JNC, and GNC. Respondents listed uses of ONCs as high-level planning aids, as background for other maps, as a reference index to other data, and as a source for boundary information. One user stated that, though ONCs where used, WDB II was the preferred source for world-wide coverage.

2.3 Current Use of Digital Data.

Of the digital data currently used by the respondents, DTED levels I and II, and DFAD levels I and II were listed by most respondents. WDB II, ADRG, WVS, and ITD were often listed. Also mentioned were DFAD 1C, DFAD 3C, DVOD, and a host of other less popular data bases.

The problems and limitations experienced with these data bases are wide ranged. They deal with the format and specification of the data, the data content, and difficulties in the processing of the data.

Lack of quality control of format and specification:

System dependent storage format and structure; difficult to import and export; difficult to develop standard software; unstructured and product specific;

Structured for the production of maps and charts, and therefore not physically continuous;

Slow processing and display due to raster storage or high attribution; slow processing due to storage structure and volume;

Inadequate attribution;

Insufficient resolution;

Insufficient coverage; unavailability of data over foreign areas; poor content for areas of sparse data availability;

Generalization limitations;

Some of these comments conflict because they come from several different sources. For example, software that operates on data that is stored in an open or general format, will also be general, which will result in longer processing and display times. This is also true of software that must operate on data of high volume, high attribution, and/or high resolution. Product specific software tends to process data more rapidly.

2.4 New Capabilities.

The following are capabilities desired by the respondents.

Scale free; ability to change scales with appropriate generalization of features; contain multiple levels of representation;

Improved methods of tracking data [redacted] throughout access; built-in source documentation (date of information, accuracy, origin, input scale, etc...); lineage and quality annotation;

Compatibility. [redacted]ibility with other products; common format; use of standard query structures;

Simplicity in structure and organization for ease in custom access; ease of use;

Consistency between scales;

Logically seamless and continuous;

Wide area of coverage;

Addition of synthetic features;

User indexes to facilitate access to data;

Ability to support high quality, color, paper output;

Better search speed;

Preservation of [redacted]; topology

Automatic product generation;

Better raster to vector and automated topology generation;

2.5 Thematic Grouping.

The themes presented in the questionnaire appeared to agree with most of the respondents. Most indicated that they were likely to use all of the themes in some way. One commented that *special use airspaces* and *aeronautical/vertical* *obstructions* would only be useful if the information was current, and another stated that they would be the least useful. Another respondent stated that *special use airspaces* and *projection grids* would not be useful.

The respondents all felt that the data would be most useful if themes were not grouped together.[1] Most respondents that the uses of the data will be wide spread, and thus require a more general storage and that grouping the data implies a specific use.

The following is a list of the groupings that illustrate the ways in which the respondents expect to use the data.

a b	land cover, hydrography;
a b c e h i	land cover, hydrography, roads, relief and city tints, culture symbols, international boundaries;
a b c e k	land cover, hydrography, roads, relief and city tints, aeronautical/vertical obstructions;
a b c g i	land cover, hydrography, roads, projection grids, international boundaries;
a b c h	land cover, hydrography, roads, culture symbols;
a b c i	land cover, hydrography, roads, international boundaries;
a b c i k	land cover, hydrography, roads, international boundaries, aeronautical/vertical obstructions;
a b d	land cover, hydrography, contours;
a j	land cover, text;
b c	hydrography, roads;
b c h	hydrography, roads, culture symbols;
b c i j	hydrography, roads, international boundaries, text;
b c k	hydrography, roads, aeronautical/vertical obstructions;
b d e	hydrography, contours, relief and city tints;
c e f i k	roads, relief and city tints, special use airspaces, international boundaries, aeronautical/vertical obstructions;
c h	roads, culture symbols;
d g i k	contours, projection grid, international boundaries, aeronautical/vertical obstructions;
d k	contours, aeronautical/vertical obstructions;
e f h j k	relief and city tints, special use airspaces, culture symbols, text, aeronautical/vertical obstructions;
f i k	special use airspaces, international boundaries, aeronautical/vertical obstructions;

Though there are valid reasons for grouping some themes of data together, the capability to add or subtract one theme from a group of themes must exist. It seems that this along with the fact that the determination of the most useful groupings is impractical lead most respondents to prefer the themes be stored individually.

1 One respondent felt that some combination of grouping and individual storage might be used.

2.6 Transformation of DCW Data.

The respondents listed several types of data translation that might need to be performed on the DCW data before they would be able to make use of it. Most listed the restructuring of CD data to an on-line/GIS database. This shows that the respondents do not intend to process the data directly off of the CD or in DCW format.

Thinning and compression of the data were also listed, along with format compaction, tessellation, projection coordinate conversion, and attribute coding and unit translation. One respondent suggested that a standard generalization and thinning routine be supplied with the data.

2.7 Elevation Data Utilization.

All respondents indicated that they require elevation data. All but one indicated that the ONC contours would not be enough. DTED levels I and II, or other DTM, were listed as alternate sources for elevation data. Most respondents indicated that they desired the ONC contours included in the DCW data, and that the contour data should match the elevation data over the same extent.

Some of the respondents indicated that the format and resolution of the DTED products were acceptable because of their wide spread use. These same respondents were mixed about the accuracy of the products, sighting that greater accuracy would be required for large scale data.

2.8 Requirements of DCW.

Standardize format/structure, glossary, and indexes of digital data;

A gazetteer capability to determine the location of named places;

A names database to support product generation;

A source identification database to support map indexing;

Good user documentation;

User oriented product format (indexed data);

Standardized utility software;

Ability to display associated symbology;

2.9 Expected Use of the DCW.

small scale applications;

replace WDB II as world-wide GIS source data with better resolution;

serve as a standard for large scale databases;

map index;

conversion to in-house format and used for product generation;

to evaluate applications for digital MC&G data;

as a storage standard that will minimize storage space, and improve efficiency in data distribution;

2.10 Suggestions and Recommendations for the DCW.

The following are suggestions and recommendations for the DCW. The comments are presented as they appeared as responses, when possible.

The distribution media should not be restricted to CD ROM. Support of traditional magnetic media should be part of the early life cycle of this product.

The initial target systems has been stated to be PC with MS-DOS. The product prototypes should also be available for PC with UNIX operating system.

The DCW database should also be available on alternative media such as 9-track tape and quarter-inch cartridges (for SUN systems). It would also be useful if released in a number of popular formats which have acted as de facto standards, such as ARC/INFO.

The hardcopy products of the prototype digital data should be distributed with the prototypes to support evaluation.

The draft specifications should be distributed as soon as possible.

A feature attribution table that maps symbol and color codes to ONC specifications could be used as a baseline to standardize feature displays for cross system comparison and evaluation.

Database should have a generic (not product specific) form.

The DCW should adopt DCIWG topological vector exchange format and ISO 8211 thus giving the standard some real encouragement.

Use FACC rather than FACS.

The project should try to address standards for large scales up to 1:50K; some of these standards may have little relevance to a data set at 1:1M, but we believe that this is an important part of the project.

A topological structure may not be necessary for all applications. Application software should allow for the stripping out of topological relationships and thus reduce the complexity of the data.

The accompanying software could usefully include the facility to downgrade the data on output (as a user option) to a chain-node structure and to "spaghetti."

2.11 Questions About the DCW.

Will the product and standard be extendable by the use? What mechanism exists to do so?

How will DCW data be compatible with other digital data products resulting from the modernization program since DCW will be derived from "aging" hardcopy maps?

How will color coding and symbology be handled in the database?

3 Listed Information from the Questionnaire.

The following subsections include information taken more or less directly from the questionnaires. This information does not allow for analysis and/or does not support the first stages of the design effort.

3.1 Current Applications of Digital Data.

The following are the information drawn from question 4...

Spatial analysis support for intelligence analysts. This includes such the applications as: situation displays, cross country movement, mission planning, route predictions, threat envelopes, and visibility.

Data integration and evaluation.

Database server for laboratory applications software systems.

Background display.

Geographic data analysis.

Overview and indexing for retrieval of DPPDB.

Production of high quality, full color paper map products.

Quick map display & visual analysis, roam, zoom, etc.

Terrain modeling and related terrain studies. Environmental modeling. Mobility studies.

General thematic map creation on scales ranging from global to urban.

Storage & retrieval of geographically referenced attribute information.

Cultural & natural feature query and retrieval.

Network studies, multivariate modeling.

Map and chart production.

Developmental work in terrain analysis.

Tactical Decision Aids.

Terrain Analysis.

Map Backgrounds.

Examination of requirements for digital MC&G data.

Small scale non-navigational paper graphics.

Incorporation into command system type applications.

TPC production.

Cooperative production.

Prototype development.

3.2 Future Applications of Digital Data...

The following are the information drawn from question 7...

Future plans for spatial data will entail the integration of current applications which will result in intermediate products and the automated exploitation of these products through processes of spatial reasoning and expert systems. In more detail we will be using digital geographic data for: area limitations, cross country movement, transportation network analysis, and terrain analysis, among others.

List: (1) More extensive and complex network analysis. (2) More detailed display and query of features. (3) Using GIS as the interface to store, query, and retrieve voluminous and complex information which can be tied to a location. (4) Answering quick questions such as: where is _____? what is at location _____? where are all of the _____ within an area? what is the area of _____?, etc. The same types of questions that may be asked of paper maps, but require considerable time and effort in answering using the paper media. (5) Incorporating temporal factors. Change detection.

Apart from continued use for map and chart production, it is envisaged that data will be used in command and control systems, terrain analysis systems, infrastructure decision support systems, and in intelligent weapons systems.

List: Mission Planning/Rehearsal, Training Simulators, Tactical Decision Aids, Map Backgrounds.

Expanded use within Navy operations. Attempting to educate Navy weapons & planning system developers on benefits of using digital data. Applications range from mission planning support to weapon system targeting and guidance. Anticipate heavy use within Amphibious arena.

Multi-product database to meet the requirements of electronic chart (ECDIS) systems, analogue chart production and miscellaneous defence requirements.

At 50K: Terrain Analysis and display products (Topological). At 250K: Terrain Analysis and display products (Topological). At 500K: Display product (Topological). At 1:1M DCW

3.3 Projects with Potential DCW Use.

The following are the information drawn from questions 10, 11, 19, and 22...

3.3.1 Project Description.

3.3.1.1 RADC/IRRP.

CATSS Digital Cartographic Applications, (DCA), (prototype laboratory); Air Flight Test Routes; ABCCC III (Airborne Battlefield Command and Control Center Phase III); C-17A Intratheater Transport Aircraft; CMARPS (Conventional Mating & Ranging Planning System; CMAG (Cruise Missile Advance Guidance); DITS (Digital Imagery Transmission System); EO-LOROPS (Ground Exploitation System for Electro-Optical Long Range System); LS (Lantirn Simulator); COMBAT TAL MC-130H Production; OBMM (On Board Mission Management); RAILS I (Relational Analysis of Internetted Linkages System Phase I); Special Operations; WS-428A II (Tactical Information Processing and Interpretation (TIPI)/IIS); TMDPS (Target Material Digital Prediction System); TRMMS (TR-1 Mission Management System)

DCA exists as one system that is a test bed for technology development and transfer into numerous other Air Force systems.

Data is needed as soon as possible for evaluation. Project exploitation should begin in FY90-91.

The world would be ideal, however, the Western hemisphere should have first priority. Some projects will require the following areas of coverage: EUROPE (4 degrees X 6 DEGREES); KOREA (2 degrees X 2 degrees); CENTRAL AMERICA (2 degrees X 2 degrees); SOUTH WEST ASIA (2 degrees X 2 degrees); NELLIS RANGE (6 degrees X 6 degrees); FORT DRUM, NY (2 degrees X 2 degrees); FORT HOOD, TX (TTD).

3.3.1.2 RASC.

PREPARE (RASC); MGIS (RASC); AUSTACCS (Australian Army)

The PREPARE project is at a conceptual design stage and due for introduction in the mid-1990s. The system will contain a number of data capture components including photogrammetry, scanning, and input from remotely sensed capture. It is expected that the system will contain an extensive range of data editing, validation, and formatting functions. The system must have the capability of managing data over RASvy's area of defence responsibility. Hardware and software configurations are yet to be determined, however, it is envisaged that data will be in a range of reference systems and that capabilities must be provided to transform data for a range of users.

The MGIS project is at a prototype stage. A number of commercial GISs are being used in Darwin with applications developed for users in the specific area.

3.3.1.3 ETL Army.

Joint Chiefs of Staff J8 Directorate Army World Wide Military Command and Control System Intelligence Threat Analysis Center.

100+ systems, data acceptable in 1992, worldwide coverage.

HW: a. SCSI Tape Drive, 200+Mbyte hard disk; b. Unix workstation, 2-5 MIPS; c. 4-24 bit displays; d. there is a shortage of drivers for UNIX CD-ROM drives.

SW: WGS 84 with capability to convert to UTM & MGRS.

Standards: Any standards adopted by DoD and/or Army up through the DCW delivery time frame will have impacts.

3.3.1.4 NOARL.

Digital MC&G Analysis Program (ongoing); Tactical Environmental Support System (under development); Tactical Air Mission Planning System (under development).

worldwide coverage, PCs and mini processors, and high-end graphics.

3.3.1.5 STU RE.

a. Advanced Mission Planning Aid (AMPA). Approximately 30 systems with ISD 1 Oct 1990. Coverage required for routes: Europe-UK-Canada; UK-Belize; Belize area including southern USA. The hardware is to be helicopter/vehicle transportable, capacity not yet known but expected to be very large with hard disk storage.

b. European Fighter Aircraft (EFA). Numbers of aircraft systems not known but expected to be several hundred. ISD 1998. Area required is estimated to be that covered by ONCs: E-16, 17, 18, and 19; F-16, 17, 18, 19, and 22; G-18, 19, 20, and 21. Systems will be aircraft mounted but nothing known of hardware/software.

c. EFA Mission Simulator. ISD 1997. No other information available.

d. Second generation _______ for data gathering and analysis. Requires small scale map database. No other information available.

Defence Geographic Database: (1) Will hold 3 data sets (1:50-1:250, 1:500, 1:1M); (2) TIGRIS (object oriented) logical data structure; (3) DGIWG topological vector exchange format; (4) FACC coding; (5) WGS 84 geodetic reference.

3.3.2 Intended Use of DCW Database.

Based on functional requirements analysis, all of the applications listed above are intended uses. In addition to the applications, however, there will be the need for generated synthetic features such as threat areas, mobility, maps, and mission routes to be added to the data base to be treated as any other features. ** Interfacing with imagery exploitation/intelligence applications. ** Intervisibility.

Replies to this question apply only to the DCW digital ONC product and not to potential larger scale products using the DCW standard: (1) terrain visualization, with or without cultural features, as the primary subject or as backdrop for other information; (2) route planning, visibility analysis; (3) reconnaissance planning; (4) locational determination; (5) briefings and situational displays; (6) locating, plotting, information overlay; (7) network studies; (8) attribute query; (9) war-gaming exercises.

List: [from question] terrain visualization, route planning, reconnaissance planning, navigation, [plus] primarily a map background, and special index to larger scale products.

List: [from the question] terrain visualization, route planning, reconnaissance planning, ground location determination, and navigation to some extent - mostly background display for electronic chart. DCW will be used within both mission planning systems and to support weapons systems and C&I for background display. Applications include line-of-sight, tactical amphibious mission planning, facilities manager, and other phases of tactical mission planning.

Our applications relate to marine navigation and naval command and control. Use, therefore, depends on the content, quality and currency of the hydrographic elements and coastal topography.

3.3.3 Intended Use of Elevation Data.

Visibility (line of sight masking).

Computation of feature elevation.

Profiles.

Slope computation.

Display (hill shading).

Mobility.

Perspective views (3D).

Production of standard map products.

Construction of digital defence products.

Line of Sight

Terrain Masking

Air/Ground Avenues of approach

3 Dimensional perspective views

Slope Maps

Line of sight calculations

Terrain visualization

Terrain masking

Mobility analysis.

Small scale charting (contour form).

3.3.4 Output Products to be Generated.

Situation displays

Visibility displays

Avenues of approach

Interdiction points

Mobility polygons

New AOI products

Color by feature

Overlay information (Intelligence, routes, hydro)

Mission planning routes

Symbolized cultural features

Perspectives views

GIS query responses

Profiles

Deconflict features

Standard colors

USAF military applications support data

The graphic display requirements range from traditional map symbolization to highly stylized schematic patterns. The only display constraints are the limits of the display device.

Composite film positives (negatives) for use in chart production (produced on raster scan equipment).

Small scale paper graphics, possibly including navigational charts.

Command and control systems.

Respondents:

- Captain Marvin Marquez, USAF, Rome Air Development Center
- Mark S. Johnson, Central Intelligence Agency
- Lieutenant Colonel R. Blackburn, Directorate of Survey, Army, Bendigo, Australia)
  Major R. Williams, Army Survey Regiment, Bendigo, Australia
- Juan Perez, U.S. Army, Engineer Topographic Laboratory
  Chris Moscoso, U.S. Army, Engineer Topographic Laboratory
- Dr. D. Drinkwater, Hydrographic Office, United Kingdom
  Ian Smith, Military Survey, United Kingdom
- John Breckenridge, U.S. Naval Oceanographic & Atmospheric Research Laboratory

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