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Future Technical Documentation Delivery Systems for Naval Maintenance and Repair

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This report describes the facilities that could be provided by a portable, microcomputer-based system for the delivery of maintenance and repair technical documentation in the Navy of the 1990's. It includes a comparison of existing documentation media (paper, microfiche, and audio-visual materials), emphasizing desirable features that should

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be preserved, and defects that should be overcome. A set of important research issues in the following areas is developed and presented, the solution of which will be vital to the realization of the proposed system:

-- interaction modes: varieties of user/system dialog to be supported.

-- datatypes: the storage formats needed for different kinds of information.

-- database structure: internal organization vs. user-perceived structure.

-- interaction devices: use of data tablet, touch, voice, and direct hookup to equipment under repair.

-- presentation techniques: graphic techniques for display - animation, windowing, information hiding.

-- travel and query facilities: provisions for navigating in the database and obtaining answers to general and specific questions.

-- annotation: ways of allowing user "personalization" of the documentation.

-- authoring: the necessity of developing sophisticated authoring tools for a sophisticated medium.

-- interface: means for integrating the system into the inventory process, and obtaining user feedback for documentation changes.

A technology estimate is presented which extrapolates from presently available technology, indicating where further research needs to be done. The formats currently employed for Navy technical documentation and the maintenance and repair "pipelines" that are followed in its production and use are reviewed in an appendix.

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1 INTRODUCTION

Military maintenance and repair, always unglamorous but essential tasks, are becoming even more important with time. Technology in general, and weapons systems in particular, are increasing in complexity and their roles in maintaining readiness are growing more crucial. This is especially true of the sophisticated electronic and aeronautical equipment found on today's ships -- for example, many weapons systems cannot function without their support computers. While numbers and complexity of equipment are increasing, manpower availability and reading skills of Naval recruits are decreasing. Research into improving Naval maintenance and repair technology is therefore imperative.

1.1 Technical Documentation

As computer scientists, our interest centers on the data needed for maintenance and repair. It is not within our purview to address the political, organizational, or economic aspects of producing, distributing, and using such data, despite the primary importance of these factors in a total systems analysis. We instead restrict ourselves to the technological issues: how the data is currently structured, presented, and used, and how its structure, presentation, and use might be improved in the future.

We call the data that technicians use as primary references for troubleshooting, repair, and routine maintenance <u>technical documentation</u> (TD). Examples of such documentation include:

- equipment descriptions,
- theories of operation,
- training manuals,
- operating instructions,
- instructions for planned maintenance,
- troubleshooting procedures,
- disassembly, repair and replacement instructions, and
- parts lists.

The users of technical documentation have broad, if not explicit, requirements and expectations. In particular, they expect a document to be:

- organized so that information needed for the task at hand is readily found,
- adaptable to their working style and skills,
- accurate, complete, and up-to-date,
- consistent with itself and other related documents,
- understandable and readable, and
- portable and durable enough to be used in the working environment.

Present technical documentation technology is primarily hardcopy (paper and microform) based, which presents the following problems:

- It is difficult to structure hardcopy technical documentation to serve multiple user needs simultaneously:

  Users with different skill levels (novice, expert), jobs (manager, technician, operator), and presentation preferences (text vs. picture orientation) cannot all be satisfied by a single manual with a single organization. Structuring hardcopy technical documentation for multiple, non-sequential modes of access is difficult, confusing, and awkward at best. This, coupled with the growth in the complexity of the systems being documented, has forced a decentralization and duplication of information among many manuals. However, the proliferation of manuals in turn creates the need for inter-manual cross referencing and indexing, and causes both logistical (paper movement) and managerial (configuration management) problems in ensuring the manuals' accuracy and consistency. Thus, the first two expectations above are somewhat at odds with one another.

- Understandability and readability are not easily accomodated by hardcopy's inflexible presentation style:

  Problems of manual writing style are well known in the military [Jablonski, 1971]. Most Navy technical manuals are in the "traditional" format [Hughes, 1977], with about 70% of their pages devoted to text written at the 9th grade reading level, and the remaining space used for charts, illustrations, and diagrams. Some attention has been focused on changing manual formats to better suit technicians' declining reading levels (see appendix A.2.1.1). Even with new formats, the lack of dynamics (animation) and the impossibility of interacting with the document prevent radical changes in presentation style that could be used to create more easily understood documentation.

- Hardcopy documentation is vulnerable in harsh environments:

  Present Naval technical documentation does not stand up well in the harsh environments commonly found on ships. Paper, while portable, is not suitable for extremely wet, dirty, or windy workplaces. Technical manuals are susceptible to permanent damage by soiling or tearing. Microform fares even worse, because it requires more careful handling (fingerprints can render it useless) and a fragile, electromechanical display device. Any new technical documentation technology which is developed must meet stringent environmental requirements if it is to see wide use on ships.

- The hardcopy production process is inadequately supported:

  Like the systems it supports, technical documentation has systems engineering aspects of its own. Documents must go through the production process of design, authoring, data capture, replication, distribution, feedback, and update. These functions require logistics and managerial support. For example, configuration management is used to keep track of document status. Present hardcopy technology suffers from the use of inadequate tools in all phases of the production process, and a lack of integration between the phases, which severely compromise the manuals' timeliness, accuracy, and consistency.

There have been several attempts to improve hardcopy technical manuals and adapt film and videotape for technical documentation [Hughes, 1977]. These programs recommend the development of electronic media as a possible answer [Frazier, 1979]. We too believe that new computer-based electronic media could provide a cost-effective solution to many of the above-mentioned problems. This belief is based on our and other researchers' prior experience with automated teaching, text manipulation, and interactive computer graphics.

Cost-effective electronic technical documentation delivery systems could have the following advantages:

- The physical volume of the technical documentation in use could be reduced.

- Distribution and update propagation could be decreased in cost, while increased in efficiency and timeliness.

- Computer graphics techniques could be used to present high content, easily understood displays.

- A database could be structured for quick access of well-specified information, using automatic indexing and classification/information retrieval techniques. The system could also interact with the user to determine his/her needs through give-and-take dialogue, and actively provide guidance to the right information.

- The system could be flexible enough to tailor itself to the user's preferences, skills, reading level, and intelligence by analyzing his or her responses as they are input.

Xerox's Learning Research Group, long involved in the development of a powerful personal computer for general use -- the Dynabook "dynamic notebook", has written eloquently of the possibilities opened by well-crafted computer-based media:

> For most of recorded history the interactions of humans with their media have been primarily nonconversational and passive in the sense that marks on paper, paint on walls, even "motion" pictures and television, do not change in response to the viewer's wishes. A mathematical formulation -- which may symbolize the essence of an entire universe -- once put down on paper, remains static and requires the reader to expand its possibilities.
>
> Every message is, in one sense or another, a simulation of some idea. It may be representational or abstract, isolated or in context, static or dynamic. The essence of a medium is very much dependent on the way messages are embedded, changed, and viewed. Although digital computers were originally designed to do arithmetic computation, the ability to simulate the details of any descriptive model means that the computer, viewed as a medium itself, can be all other media if the embedding and viewing methods are sufficiently well provided. Moreover, this new "metamedium" is active -- it can respond to queries and experiments -- so that the messages may involve the learner in a two-way conversation. [LRG, 1976]

It is this facility that we would like to apply to technical documentation: the dynamic instead of the static, the conversational and active instead of the nonconversational and passive.

1.2 Purpose and Organization of this Report

The purpose of this report is three-fold:

First, to develop a characterization of technical documentation with which we can describe both the interaction between a technician and his or her technical manuals, and the inherent capabilities of the documentation media in current use (Section 2). Specifics on the kinds of documentation used in Naval maintenance and repair, the actual manual formats employed, and the "pipeline" used to produce them are included (Appendix A).

Second, to sketch the high level architecture of a future technical documentation delivery system, discuss the research problems that need to be solved to make its development possible, and estimate the technological advances necessary to implement the future system (Section 3.1).

Third, to explore the close relationship between the disciplines of design, training, and maintenance and repair, suggesting the expanded role that the future technical documentation delivery system might play as an integral part of the design and training processes (Section 3.2).

1.3 Basis

The information and opinions presented here are based on our experience of more than a decade with interactive computer graphics and text processing, and a variety of reference sources.

A literature search was performed and yielded materials from many areas: maintainability engineering, systems data engineering, human factors, and previous studies of military maintenance and technical data. These studies included reports of several military programs oriented toward the improvement of technical documentation for training and maintenance support: the Navy Technical Information Presentation Program (NTIPP) [Hughes, 1977], the Army's Skill Performance Aids (formerly, Integrated Technical Documentation and Training) program (SPA) [ARTADS, 1977], and the Air Force's Automated Technical Order System (ATOS) [ATOS, 1976]. All three programs stress the need for integrating the development of technical documentation with the design and development of technical equipment. In addition, they are aimed at improving the match between the user's needs and abilities, and technical documentation data and its presentation. The reports resulting from these programs examine the state of current military technical documentation from the points of view of production, content, usage, and distribution.

An additional source of information was our own personal observations made on visits to two ships: the U.S.S. Puget Sound (AD-38), a destroyer tender whose primary mission is maintenance and repair, and the U.S.S. Independence (CV-62), an aircraft carrier. These on-site visits were made in October, 1978, while the ships were in port at Norfolk, Virginia. The visits were made for the express purpose of examining how maintenance and repair is done in actual shipboard environments. On both ships, we spoke to officers and enlisted personnel, to try to form a picture of typical maintenance and repair operation. A more detailed summary of these visits can be found in [Brown, 1978].

As valuable as these ship visits were to forming our perceptions of Naval maintenance and repair, we realize, of course, that two visits alone are scarcely sufficient to obtain a representative sample of a "typical" shipboard environment, if such exists at all. Indeed, one observation resulting from the visits was the wide variation in operating procedures both between ships and even between departments on the same ship. Nevertheless, we feel that the exposure to actual maintenance and repair practices obtained from these visits provided a useful background for our study.

2 A COMPARISON OF EXISTING DOCUMENTATION MEDIA

In order to gain a better idea of the possibilities for computer based documentation, it is helpful to examine the inherent capabilities of the existing documentation media themselves: the limitations of paper manuals, microform, and traditional audio-visual media; their advantages and disadvantages.

Technical documentation may be characterized by its:

- physical characteristics -- the document's medium, size, shape, weight, and "feel",
- data types -- the kinds of information contained in the document,
- database structure -- the manner in which data types are encoded, grouped together, and cross-referenced/linked,
- interaction devices -- the interface through which data are presented to and obtained from the user,
- display format -- the appearance of information presented to the user,
- travel facilities -- the means for exploring and traversing the database,
- query facilities -- the provisions for obtaining specific information from the database,

- annotation facilities — the means by which the user adds autographed information to the database, and

- personalized presentation facilities — the means by which the system alters its manner of response to suit the needs, either expressed or implied, of the user.

These characteristics are all closely interrelated, some more than others, depending on the medium. We examine first existing media, and then future computer based media, in terms of them.

In the following discussion, it will be necessary to distinguish between those organizational structures and interactional capabilities imposed on the documentation by the author and adhered to by the user, and those provided for and enforced by the documentation delivery system itself.

Consider, for example, a reference in a paper document. It will, typically, be either a precise page or section reference in the document or another volume, or a subject reference. The reader, in following the reference, must find and turn to the referenced page, and, in the latter case, must first resolve the subject reference to a page or section number by consulting an index. This is a time consuming and potentially error prone procedure. Computerized documentation can provide the ability to instantly "jump" to the referenced information. The searching is done for, not by, the user, who need never be aware of where the referenced material is physically located. Many of the research problems which we are addressing involve the development of means to shift the responsibility for accomplishing such tasks from the user to the documentation system.

2.1 The Paper Paradigm

Traditional paper documentation provides useful paradigms for a rich set of organizational structures and interaction capabilities. The central role paper still plays as an information medium is responsible for behaviors and expectations on the part of its users that must be dealt with in the design of future documentation systems. Hence paper serves as a benchmark and point of departure for the information presentation techniques we are investigating.

• Physical Characteristics, Datatypes, and Database Structure

The word "manual" is derived from the Latin <u>manuale</u> -- something that can be held in the hand. As such, the paper manual is a compact and convenient package for technical information. Although standard data types (e.g., English language text) have arisen through convention, the two-dimensional information carried by the printed page, and its format, are limited only by practical considerations: the manual should not be unwieldy in size or contain excessively complicated or dense information, which may be hard to read or understand.

An individual manual is organized as a randomly accessible, ordered set of identically sized pages, possibly interspersed with oversized foldouts. The author may segment verbal and pictorial information into sections, chapter, paragraphs, sentences, tables, charts, schematics, drawings, and photographs. Arbitrarily complex cross referencing schemes may employ indices, tables of contents, and inline references.

• Display Format and Interaction Devices

A page is its own display; the reader's hands, perhaps holding a pen or pencil, are the only "interaction devices." Paper is unique among present documentation in that, barring external references to other material, it is completely self-contained. As is the case with other static media, its physical organization and display format are inextricably intertwined. Information stored on a page is displayed on that page -- "what you see is what you get." Only automated (computer based) media which interpose processing power between the stored information and its display can reformat information and conceal the details of its actual location from the user.

• Travelling

Travelling through information provided by a paper manual is entirely up to the user, who may adapt any of a variety of approaches as appropriate:

- reading "from cover to cover" or reading sections of text in a prescribed (not necessarily linear) order,
- following proceduralized checkout or troubleshooting sequences,

- skimming through text, illustrations, tables of contents, or indices,
- linearly thumbing/flipping through its pages.
- direct access "jumping" to a referenced page through information provided by an inline reference, concordance, or index, or
- referring to another volume.

Intimately associated with travelling is the activity of "bookmarking" important pages for future reference. This may be done by the user or may be provided for by the documentation itself via thumb indices, tabbed inserts, or colored pages. The chapter headings, page numbers, and even the "feel" of the manual when opened to the current page indicate the reader's location, as well.

• Querying

Searching for specific information (querying) a paper manual is solely the user's responsibility and may involve:

- looking for information that is known to be in a particular place,
- looking for a section that is known to be somewhere in the manual,
- looking for information that is only suspected to be in the manual,
- asking what the manual contains, or
- asking where in the manual you are, where you have been, and (by looking ahead) where you will be — your itinerary.

In searching, the user relies upon the manual's structure, established by its segmentation into chunks of information linked together by whatever cross-referencing or indexing there is. Because paper is a static medium, a manual may be hierarchically organized in only one way (from cover to cover), even though the information that it contains might conceivably be ordered in any of a number of other hierarchies, some of which might be better suited to the reader's current needs. In addition, there is no way to filter out information that is extraneous to the search. The reader who is referred to several pages in the manual must actively ignore surrounding pages and unneeded portions of the referenced pages.

• Annotation

Annotation is the principal method by which a user (as opposed to the system) personalizes a document. The annotation capabilities provided by paper are particularly flexible (assuming the user is allowed to mark up his/her own copy, often prohibited in a one-copy-per-shop environment).

Since information is stored as ink on paper, the user may make marginal comments, circle, underscore, point, cross out, (re)write/draw. The form in which annotations appear itself provides information and can be used to draw distinctions:

- handwriting -- The style of handwriting distinguishes between different annotators or different intent/mood on the part of the same annotator. Cursive marginalia may contrast with bold printed warnings.

- color -- Color coding may be used to clarify signal paths in a schematic, group logically related subassemblies, or emphasize important information.

- shape -- Underscoring, circling, boxing, pointing, and shading may each be used for different effect.

- size -- The relative size of an annotation might indicate its importance.

Note that the annotator and reader maintain responsibility for imparting meaning to the annotations when they are created and read. In addition, annotations are not checked for consistency and are in no way integrated with the information to which they refer, except insofar as they are overlaid on it. It would be more proper to say that the annotations are associated with the display format, though they may have been intended to refer to the information being displayed ("what" is being said), without regard to its manner of presentation ("how" it is said). Suppose that the reader circles a reference to a testpoint in red. The intention was to indicate an important reference, but the page only bears a line that was drawn about a collection of marks representing particular words. The reader must be aware of the annotator's intentions and remember what the red circle signifies.

Ink-on-paper annotations are not selectively viewable, and may only be propagated to revisions of the annotated material by lengthy and error prone hand copying.

• **Personalized Presentation**

Attempts to personalize a paper manual's presentation typically involve the creation of different versions for varying skill levels, or the hand assembly of relevant short sections in a looseleaf binder or packet to suit a particular job. (See the discussion of the "control work package" concept in Appendix A.1.3).

2.2 Microform

Microform is the most popular alternative to paper. Its primary advantages are compactness, which makes it easier to store and distribute; simple and rapid updating, eliminating the need to apply individual page changes at the maintenance level; and reproduction costs lower than those for comparable paper documents. Since it is a newer technology, there has been greater standardization of formats, and better configuration control.

A static 2-dimensional medium, microform is typically used to provide photoreduced copies of originally paper-based documentation. Consequently, microform users interact with their documents in much the same way as they do with paper, with two notable differences:

- A clumsy electromechanical reader mediates between the user and the document, serving only to enlarge and project the images it contains, without providing any processing power (some systems have indexing facilities that allow automatic retrieval of a frame whose number is entered by the user).

- The annotation capabilities of paper are completely lost, except insofar as reader/printer hard copy may be marked up.[1]

Additional disadvantages include the following:

- The need for indexing is more critical with microform documents, since the user cannot view them without the use of a reader.

- Photographs do not reproduce well in general.

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[1]But note that none of the printers we saw in the electronics shop on the aircraft carrier were operational, a source of considerable frustration to technicians.

- Color, which is used in certain types of manuals, is very costly to reproduce, and therefore rarely used.

- Some kinds of information, such as wiring diagrams, which span multiple "pages" do not lend themselves to the medium, since most display devices can show only a page at a time.

- Reader/printers do not offer adequate frame to frame correlation for copies of continuous multi-page material.

- "Page flipping" can only be accomplished in a clumsy fashion. Automated readers tend to over or undershoot the location of a desired frame.

- One cannot have the equivalent of several manuals open side by side.

- The display devices are not yet portable or rugged enough to be used in hostile environments.

- Like paper documentation, all information is static.

However, microform is not just a new way to economically store the same material as paper. Novel display formats could take advantage of the large two dimensional information plane presented by fiche. For example, a troubleshooting sequence could instruct the user to proceed vertically down the fiche, for high level troubleshooting, and horizontally across for instructions required for in-depth analysis. The horizontal strip can contain full sized schematics and charts, too bulky for inclusion in a paper manual (though maneuvering in a schematic can be difficult because of the reader's fixed sized display window). This layout scheme was used in the Army's MICROM program for Field Level manuals employed in missile component checkout [Hess, 1969].

2.3 Traditional Audiovisual Media

Although traditional audiovisual aids, such as film, slides, and audio recordings, have been used successfully in training, unsatisfactory results have been achieved in maintenance and repair experiments. An experiment reported in [Elliott, 1966] is typical. Successive index cards containing proceduralized troubleshooting information were presented to subjects when they entered the number of each desired card into an electromechanical retrieval device. The number of the next card was determined by the result of the tests ordered by the previous card selected. Members of one group received the card itself, members of the other group were read the information that it contained (with the option to have the whole card reread from the beginning as many times as requested). The audio group fared significantly worse, spending more time and making more errors.

One possible explanation for the inferior performance of the group provided with the audio documentation is that the information itself was poorly suited for audio presentation. However, because of the technology available at the time, the audio group was at an unfair disadvantage: the spoken repetition of an entire card was an inadequate substitute for the rereading of isolated words and phrases possible for those who received written information. Audio group members had to waste time listening to parts of the instructions that they already understood if a repetition was requested, and may sometimes have failed to request needed repetitions as a result. Similar problems could occur in the presentation of animated pictorial data via film or videotape. For example, a desired frame of a filmed animation might only be reached by watching all the preceding material.

The largely sequential "lockstep" presentations useful in training won't suffice for maintenance and repair activities. Traditional audiovisual media do not by themselves provide adequate facilities for the quick random access needed in proceduralized troubleshooting to move both between and "inside of" selected steps. Therefore, most approaches to structuring and quickly accessing a "troubleshooting tree" database of audiovisual materials use computerized retrieval, even though the "leaves" of the tree are traditional media.[2] Despite the use of traditional media for information storage, the resulting system would be a computer-based hybrid with none of the sophisticated facilities proposed in Section 3.1.

---

[2] Examples of such systems may be found in [SALT, 1979]. Even standard Kodak "Carousel" slide projectors may be ordered with a microprocessor controller for random access.

ADVANTAGES	DISADVANTAGES
Paper	
• Reliable	• Excessively bulky in quantity
• Simple	• Difficult and expensive to distribute and update
• Familiar	• Limited structuring facilities
• Self-contained, individual manuals are highly portable	• Static, inflexible, nonconversational presentation
• Rich annotation facilities	
Microform	
• Cheaper to reproduce and distribute than paper	• Bulky, clumsy reader/printers often malfunction
• More compact than paper	• Only one page at a time is viewable
• More easily updated in the field than paper	• Printers don't handle multi-page schematics well
	• No annotation facilities
	• Photographs and continuous tone art reproduce poorly
	• Static, inflexible, nonconversational presentation
Traditional Audiovisual Media	
• Exploit sight/sound	• Clumsy electromechanical systems are failure prone and expensive
• Audio can obviate eye contact	• No smooth "give-and-take" interaction
• Animation can better illustrate time-varying phenomena	• Inadequate facilities for random access retrieval

Table 1: A Comparison of Existing Documentation Media

3 DIRECTIONS FOR FUTURE RESEARCH

In this section, we present two projects which will serve as the focal points for our automated technical documentation research:

- the development of a computer based medium for the storage and presentation of technical documentation. This involves experimentation with forms of structure and presentation.

- an investigation into the relationship between design, training, and maintenance and repair. This relationship is important in that it strongly affects the form of a new technical documentation medium, both in the interaction modes it should support, and in the way it is ultimately used (e.g., for training, maintenance and repair, or both).

3.1 Computer Based Media

We propose that the development of a computer based technical documentation medium could eliminate or reduce problems of paper volume, distribution and update, inflexibility, and lack of structure. However, a radically new medium whose ultimate goal is the large scale replacement of paper must:

- provide an improvement in user capability over paper manuals,

- be portable and rugged enough for use in potentially hostile environments,

- be easy to use and require minimal user training to operate, and

- include tools for low-cost creation and production of new technical documentation.

Most of these goals will require significant research and development to achieve. The components that will comprise this new electronic medium are intended for development in a ten to fifteen year time frame. It is doubtful whether paper can be completely displaced by any new media within this time period.

Since a user's attitude towards documentation is in large measure shaped by prior experience with conventional media (most often paper books), an effort is made herein to suggest new capabilities that might be provided by computer based media. However, many of the existing modes of access of paper documentation should be retained, because of their familiarity and essential simplicity. Clearly, a successful new medium should merge these conventional access modes with new ones that convey information more effectively.

One way of determining the optimal combination of new and old characteristics is through experimentation. In the following pages we sketch the high level architecture for an experimental technical documentation delivery system of the future that will serve as a point of departure for our research. The functional capabilities of the architecture will be presented, along with a set of research questions that will provide the basis for experiments within its framework. The reader should keep in mind that not all the technology needed for such a system currently exists — considerable extrapolation of current technology is imagined.

The reader is referred to a specification for the design of a technical documentation system for the Army, that makes use of available technology [Gurwitz, 1978]. Many of the ideas of that system are expanded here. In fact, that system could be thought of as an "interim" technical documentation system (in the sense of [LRG, 1976]). However, where its capabilities were necessarily limited by available technology, the system described here is not.

A second proposal for a computer based technical documentation system is presented in an excellent report prepared at the same time as ours for NTIPP by Behavior Technology Consultants, Inc. (BTC) [Frazier, 1979]. The proposed BTC system would use a small mini- or micro-computer based terminal with high quality graphics capabilities, local memory, and magnetic disk mass storage. The terminal could communicate with a central technical documentation archival computer, but is designed to operate primarily in a standalone mode. User interaction would be accomplished with a specialized function keyboard for input, and a combination of CRT and other medium to high resolution graphics output devices. The design emphasizes the use of existing technology (microprocessors, disk storage, CRTs) in a semi-portable device (weighing 80 pounds) for presenting primarily procedural technical data with backup reference information.

While we are in basic agreement with the aims of the BTC system, we feel that their discussion underemphasizes several key issues:

- Though their system is targetted for the mid-1980's Navy, the time and effort required for the development of system software and the creation of documentation suitable for the system's presentation capabilities, makes the deployment of practical shipboard systems by the target date seem overoptimistic.

- The BTC report makes little mention of the problems involved in creating documentation designed to take full advantage of the new medium. As stated in section 3.1.4.1, the creation of a structured database for a large volume of text and graphics that is easily accessible is a difficult, resource intensive problem.

- No consideration is given to the size of digital databases required for supporting sophisticated presentation of technical documentation. This is an especially serious concern given the expected explosion in size due to increased graphics content of the new documentation and the use of existing storage technology.

As part of our research strategy, a testbed system will be developed. Though it employs technology similar to that of the proposed BTC system, it will be used to explore sophisticated techniques such as animation, annotation, personalization, and nonsequential travelling that were not considered in their report. However, this testbed should not be construed as a prototype of our proposed technical documentation delivery system, but rather as an experimental vehicle for developing answers to research questions which will be refined and augmented as our research progresses.

3.1.1 TESTBED SYSTEM

The experimental system to be used as a research vehicle represents a laboratory microcosm of the problems to be faced in the development of the future technical documentation delivery system described in the next section. The testbed will initially be built with existing technology: midi- and minicomputers with magnetic disks for document storage and processing, and color raster graphics equipment with conventional interaction devices (keyboard and data tablet). It will have many of the database, interaction, and presentation characteristics described in the following sections. The testbed system will enable us to experiment with these techniques and devices, and add new capabilities as our research progresses (e.g., an optical disk for compact mass storage, a touch sensitive display and voice input/output for more natural interaction, and advanced annotation facilities).

A major problem to be faced in the development of the testbed is the initial selection of a database with which to experiment. Initially, a small (500-1000 page with approximately 100 pictures) database derived from existing Navy technical manuals is contemplated. The problems we will encounter are typical of those involved in retrofitting existing technical documentation to a new medium (see Section 3.1.4.3):

- selection of an experimental database which is both representative of Navy technical documentation and extensible,

- determination of a transfer strategy which will make full use of the testbed's structuring and presentation facilities,

- capture of text and pictures in machine readable form, and

- imposing structure on the database.

3.1.2 FUTURE SYSTEM: CHARACTERISTICS

The main function of the future technical documentation delivery system is the storage and access of a large amount of structured technical information in the form of text and graphics in arbitrary combination (see Appendix A.2.3). The inclusion of annotation facilities means that it is not simply a read-only device interpreting a "canned" technical documentation database, but rather allows the technician to "mark up" the documentation, as he or she would paper technical manuals.

The system should be able to operate in a stand-alone mode, with a self-contained database that comprises the equivalent of one or more technical manuals, held on some removable storage medium. In addition, it should be able to operate as an "intelligent terminal" which could be connected to a central database of technical information. This might be a shipboard technical library or a more centralized land-based archive connected to the ship by satellite link. In this mode, a technician could "plug in" to the central database and receive a "package" of technical documentation that could be buffered locally for use during a particular maintenance and repair task.

The unit should be small and lightweight, for easy portability. It should be battery powered and rugged enough to survive in a hostile environment, such as the boiler room of a ship. A high resolution flat panel color display could serve as the output device. Input devices might include a touch sensitive interface, overlaid on the display, for picking and drawing. Depending on the level of sophistication of the input capabilities desired, a keyboard might be included. Typically however, a simpler input device for limited alphanumerics or voice input would be needed for interacting with maintenance and repair data. Most of the user control and data access functions could be accomplished using simple menus with selections indicated by picking or voice input. The device would contain one or more local processors, fast primary memory, and accomodate some removable secondary storage medium (e.g., magnetic or optical disk). An I/O port would allow connection to remote processors or the central database.

The scale of the unit envisioned here is exemplified by Xerox PARC's Dynabook project [LRG, 1976], whose goal is to develop a portable personal computer for general information needs.

3.1.3 FUTURE SYSTEM: MEDIA RESEARCH PROBLEMS[3]

3.1.3.1 Interaction Modes

The system should accomodate three major interaction modes:

- Free format travelling/querying.

  If the user is looking for general information, provision should be made for presenting and choosing possible paths for further exploration at each step, narrowing (or broadening) the search when necessary, and making note of topics of interest that must be momentarily bypassed. On the other hand, if specific information is desired, the user should be able to access it quickly without the need to tediously retrace the same hierarchy by which it may have originally been found.

- Proceduralized checkout and troubleshooting sequences.

  The user can be guided through maintenance procedures whose specific order of performance is important. The material next presented may be dependent on evaluation of the user's responses.

- Training.

  Tutorials, practice problems, and graded test questions much like those of present Computer Aid Instruction (CAI) systems, such as the University of Illinois' PLATO system [Sugarman, 1978], require facilities similar to those needed for proceduralized maintenance and repair. The

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[3]The problems discussed herein include both those that we intend to tackle ourselves, and those that must be solved by other researchers before a system with the proposed abilities can become a reality. The word "we" is used in some places to indicate which parts of particularly difficult problems we will approach.

documentation system could be used from the start in school training, initially to instruct the technician in its own use. In addition, training sequences provided onboard could allow technicians to acquire the job skills needed for promotion, without leaving the ship.

3.1.3.2 Data Types

A variety of data types must be supported by the technical documentation tool. Their choice, based on the database to be presented, will determine the internal data structure and presentation techniques required. For example, text, which may be represented by a string of 8-bit codes, requires much different processing than a vector stroked line, or a raster representation of the same line. Differentiating between these data types permits them to be handled in a computer system in a way that is optimal for each representation.

Based on our investigation into the content of military technical documentation (see Appendix A), we have identified the following potential data types:

- text,
- 2-D line drawings,
- 3-D line drawings,
- bit map raster drawings and photographs,*
- sound cues, and
- references.

These primitive data types can be grouped in collections or structures:

- A frame could be defined as the information needed for a single static display, analogous to a page in a book. This might consist of combinations of text, graphics, etc.

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*Raster displays use arrays of bits, called "bit maps," in which each picture element ("pixel") or distinguishable point on the display corresponds to several bits in memory. This data, typically 4-12 bits per pixel, determines brightness levels in monochrome systems, and hue, saturation, and brightness in color systems. The bit map can also be treated as individual 1-n bit planes into which data can be written or read separately. For more information, see [Newman, 1979].

- A *sequence* might consist of a group of ordered frames which can be accessed one after another, for purposes of training or proceduralized instruction.

- An *animation* might be a sequence of 2- or 3-D graphics that could be run together to give a motion picture effect.

- A *document* could be a logically coherent unit containing arbitrary primitives, structures, and references both internal to itself and to other documents.

- A *database* (see Section 3.1.3.3) would be a collection of documents and their cross-references, traditionally an ordered sequence, a hierarchy, or a directed graph.

The selection of a powerful set of primitive data types and structures and the development of efficient methods for storing, processing, and presenting them is a major near and long term research problem.

3.1.3.3 Database Structure

There are two levels of database structure present in our hypothesized system, both of which will require substantial research.

The *internal* (implementation) structure is the way in which (collections of) primitive data types are physically stored and cross-referenced. Of primary concern here is the development of encoding formats that provide efficient and flexible access to information.

The internal structure is transparent to the user, who perceives only the *external* structure: the way in which the interaction facilities provided by the system combine to produce the user's mental conception of the data with which he or she is interacting. This user-perceived external structure must be easy to understand and maneuver in, while providing as much power as possible. These goals often seem to be at cross purposes; their resolution will be necessary to create a system that is useful, as well as usable. The more general the structure, the more the possibility for confusion. If a system is not comfortable and natural to use, it will not be used. A Boeing Company study, conducted to gauge the readability of the technical manuals then in use, showed that 16% of the aircraft mechanics questioned *never* used technical manuals [Jablonski, 1971].

Brown University's File Retrieval and Editing System (FRESS) [van Dam, 1975] and MIT's Spatial Data Management System (SDMS)

[Bolt, 1979; Herot, 1979] evidence two different approaches to external database structure.

FRESS, a text manipulation system with information retrieval capabilities, allows its users to imbed structuring information (known as "hypertext" [Nelson, 1974]) in their data and manipulate this structure as they would normal text. Hypertext may consist of hierarchical blocks, cross-references, annotation tags, and keywords that can be specified in Boolean expressions for retrieval. Thus, the information can be structured as an arbitrarily complex "directed graph" which supports information retrieval in a database of text and line drawings. The ability to manipulate the structure like any other information in the system gives the user a powerful way of travelling through the database. By providing information hiding capabilities (see Section 3.1.3.5), the structure can be used to guide users through the data in an active manner, potentially useful for proceduralized troubleshooting.

SDMS structures graphical and aural information in an open-ended "dataland" which the viewer can explore by "flying" through it with the aid of several interaction devices. Objects in the database are represented by graphical symbols that are fixed in spatial orientation with respect to each other in the data space. A multi-level of detail display allows the user to examine the data represented by the symbols through "zoom" and "pan" operations.

The database structure problems that need to be solved are computationally tractable and demand no special hardware; however, they will require much experimentation beginning with the earliest stages of our work.

3.1.3.4 Interaction Devices

Is the choice of interaction devices purely a matter of personal taste and preference or are there some that make possible an ease of interaction that would be otherwise unobtainable? We are interested in at first using commercially available hardware and established algorithms to gauge the potential, tradeoffs, and computational load of devices that exploit diverse modalities:

- Touch sensitive displays [Bolt, 1977] (e.g., those manufactured by TSD Display Products, Inc. and Elographics, Inc.) can provide a wordless approach to spatially oriented interaction that is more natural than that achieved with keyboards, knobs, switches, or joysticks.

- Character recognition algorithms can allow verbal annotations to be input from a data tablet or touch sensitive display and stored/processed in the same fashion as the annotated text itself. For example, the input annotations could be scanned, along with the original text, for the occurrence of specified words. Hand-printed input can also be used to eliminate batched keypunching from forms (e.g., the "2-kilo" forms discussed in Appendix A.1.3) filled out by service personnel without requiring them to learn how to use a typewriter keyboard.

- Voice interfaces (e.g., those manufactured by ATO, Dialog, and Votrax) can make possible "hands free" information interchange without eye contact. Studies should be done of the vocabulary, syntax, and semantics associated with maintenance and repair procedures for specific (classes of) equipment. What power must be provided? Much maintenance and repair may require only "word at a time" interaction for which much simpler solutions exist than those demanded by continuous speech understanding.

  Unlike handwritten or touch input, voice interfaces have the potential to radically influence the structure of future documentation. At first, voice can be used as an alternate means of communicating information to users who are less comfortable with written instructions, and for providing prompts or accepting simple commands. Voice (and, more generally, audio) interfaces could later be used to continuously monitor the maintenance and repair process, offering (unsolicited) corrective feedback.

We intend to acquire a touch sensitive display early in our research, but a lack of adequate computational power and hardware expense preclude our use of handwritten input and voice, respectively, for the near term.

Future work could address the following difficult problems:

- In what ways can the equipment under test/repair be directly interfaced with the documentation? "Plugging the problem into the system" could generate side by side displays of expected versus actual measurements. Can expensive, exhaustive automated testing equipment (such as the Versatile Avionics Shop Tester (VAST) system used aboard the U.S.S. Independence [Avionics, 1978]) be replaced by systems that use a "human in the loop" to handle whatever manipulation and deduction that has not already been automated?

- The documentation might include programs for sophisticated "intelligent" tools used to perform repairs. When diagnosis is complete, the documentation system could interface with and specify the operation of complicated repair equipment that could, for example, take advantage of the regular 2 1/2-dimensional layout of electronic systems. Organizational level personnel might only need to position the tool on the malfunctioning equipment, without having to understand its operation. A family of such program controlled (micro) manipulators might be envisioned, each capable of a variety of repair procedures. For example, one such tool might use a motorized shaft to precisely adjust trimmer potentiometers and capacitors. By storing maintenance information in the equipment under repair itself, comparisons of its current state with its unique electronic "signature" could help assure precise individualized repairs. Maintenance and repair schedules might also be kept in the equipment and tool. Computerized documentation can thus be a vital first step toward minimizing, and eventually eliminating, the need for trained human assistance in many repair procedures.

3.1.3.5 Display Format and Presentation Techniques

The techniques of highlighting, information hiding, animation, and windowing can help make the information presented by the system useful and understandable to a wide class of users. Although, with the exception of animation, their implementation is often simple, research needs to be done to determine how to use them effectively.

• Highlighting

There has been much research on and practical experience with the graphic effects needed to effectively highlight data in a display [Christ, 1975; Morgan, 1963; Morris, 1979]. This is especially important in complex, frequently changing displays. Techniques used for graphics highlighting include blinking, intensification, and the use of color. In summary, color seems to be the best all around highlighting device for complicated material. Therefore, the technical documentation system would use a color display.

Attempts have been made to appeal to senses other than the visual:

- Sound cues have been used for highlighting in combination with graphic displays to reinforce spatial effects [Bolt, 1979].

- Tactile feedback has been employed to indicate the user's position in a displayed two dimensional force field by exerting X and Y forces on a knob that the user moves to explore it [Brooks, 1977].

The main difficulties in choosing proper highlighting techniques are in determining their subjective effectiveness (i.e., which techniques to use when for greatest effect).

• Information Hiding

"Information hiding" is the selective concealment of information in a display, a technique that can be used to reduce confusion in a crowded display, to differentiate between multiple levels of detail, to provide keyword-protected access to selected sections of the document, or in a training system, to hide answers to test questions or material a student is not prepared to handle. Information hiding can be implemented in several ways. In text oriented systems, information is hidden by making smooth transitions between surrounding non-hidden text portions. In graphics systems, information may be hidden by removing selected items in a display.

Graphical information hiding may be combined with a "logical pan/zoom" facility that enables an imaginary window to be placed over a part of the display (e.g., a large block diagram), which is enlarged to fill the window. As the displayed portion is "zoomed in" on, more detailed views of that section of the image pop into view. This creates a "2 1/2-D" effect, in which the pseudo-third dimension is level of detail. This can be very useful for allowing a user to concentrate on a section of a complex image and selectively choose the level of detail he or she wishes to see. Conversely, it can be used to provide an overview of a diagram, while hiding potentially confusing detail. It can also allow large, complex images (e.g., schematics) to be displayed on small screens without sacrificing detail to limited resolution.

An example of this type of information hiding can be seen in MIDAS [Gurwitz, 1978a], which lets users logically pan and zoom over an animated block diagram of a micro-computer system. 2 1/2-D has also been used to access hierarchically structured data in a graphics database [Bolt, 1977a]. In this application, the zoom capability was used to travel between levels in a tree structured database of raster pictures.

The use of information hiding techniques greatly depends on how the database is structured, and subjectively on how complex the "chunks" of information to be displayed are, and how smooth the transitions between chunks should be. A smooth "pan/zoom" facility like that used in MIDAS is visually pleasing, but is it necessary for the effect to be successful?

• Animation

How can dynamic displays, unknown in static paper documentation, be effectively integrated into the system? What use can be made of "cartoon" animations, dynamic parts explosions/implosions, simulations, selectable views of the same object obtained by "flying around it"?

Animated block diagrams could be used to illustrate the dynamic (and often asynchronous) "handshaking", or control interface between digital devices. MIDAS, mentioned above, exemplifies this kind of animation. Can the specification of such pictorial user-controlled simulations be automated? A digital system may be unambiguously specified at the level of control and data flow using the Instruction Set Processor (ISP) notation [Bell, 1978; Barbacci, 1979], and the specification compiled to produce a simulator. Research could be done into the possibility of automatically generating an animated visualization of the architecture from its ISP which could be driven by the simulator to display data transfers and control operations. The ISP would probably have to be extended with some high level animation primitives.

3-D exploded views are often used in assembly/disassembly instructions. An animated parts explosion diagram under user control would be useful in illustrating the interconnection of parts in a complex mechanical assemblage. How can such highly structured animations be specified? Interpolated key frame animation provides a basis. How can the system simulate the working of even simple mechanical components? This is an intrinsically hard problem.

How realistic and smooth do animations have to be? There is a wide spectrum of possibilities between the painstaking full animations of the old Disney studios and slowly interpolated, ten frame sequences, such as those employed in the Xerox PARC Superpaint system [Shoup, 1979]. This question is of great importance, since the generation of arbitrary, smooth, high resolution color animations would place tremendous demands (by today's standards) on the system's computational power and storage capacity. The complexity of the authoring tools required for creating animations depends on the level of sophistication desired, as well.

• Windowing

"Windowing" refers to the division of a display surface into one or more areas ("windows") into which possibly unrelated information may be mapped.

What clean ways can be developed for graphically presenting unanticipated combinations of information? Consider the technician who requires simultaneous display of several charts (separate pages in one or more manuals). Existing computer-based solutions involve:

- menu-picking to swap the contents of a single display window,

- multiple contiguous windows (such a display would correspond to a technician's spreading out several manuals for side-by-side reference), and

- overlapping windows that simulate the clutter of an office desktop by allowing arbitrarily sized windows to partially or completely obscure each other under user control [Teitelman, 1977].

How can a custom "nonce display" — one that is not planned for when the documentation was created — be synthesized from relevant sections of charts, tables, and text, taken from possibly disparate databases? The user might indicate the needed information by circling it. If the display is to be constructed from sections of several tables, material might have to be altered in size, reordered/sorted, or manipulated in other ways in order to be effectively integrated. Such facilities will not be of much use unless they are easy to control.

3.1.3.6 Travelling

The kind of facilities provided for traversing the database play a crucial role in determining the documentation's usefulness.

"You are here" assistance must be provided to help the user maintain his/her bearings in an information-rich environment. One possibility is a dynamically changing symbolic 2D (or 3D) map that reflects the layout of the database, indicating the user's current position [Bolt, 1979]. How does one generate a canonical display of this type from an arbitrary directed graph?

The user should have the ability to "bookmark" important locations, leaving a "trail" of places that may be retraced sequentially or accessed individually [Bush, 1945; van Dam, 1975]. System-provided trails could smoothly lead the technician through proceduralized troubleshooting sequences.

Like the closely related problems of choosing and imposing a structure on the documentation database, the above will require much experimentation.

There are other, even more challenging problems whose solution could only be attempted when our repertoire of structuring techniques has matured. For example, could the ability be provided to simultaneously navigate in multiple databases? With such facilities, a technician familiar with the maintenance of one device could compare/contrast it with another similar, yet unfamiliar, device. Incompatible sections of the two databases might be noted as such and bypassed, while material amenable to comparison is processed and displayed. Must the facilities for coordinated parallel travel be anticipated and provided for in advance or can it be done dynamically, on request?

3.1.3.7 Querying

The provision of powerful query facilities requires that the system should be able to automatically present an "index" of the information available in the database. This automatic indexing could be menu based, presenting major topics which could then be broken down into subtopics by picking choices from successively displayed menus. An easy way of travelling to and from the index and the various chunks of information it references would have to be provided (e.g., the NLS tree walking functions [Englebart, 1973]).

At first, index entries could be entered by hand, with assistance from the authoring tools discussed in Section 3.1.4.1. In addition, material might be indexed for keywords by the system itself. This approach is already being taken in software running under Bell Laboratories' UNIX operating system. A collection of articles and papers stored online, containing over 5,100,000 words, was automatically indexed for all words not among the 100 most common in the English language. The resulting 19,000 keywords can be used in combination to select a document whose title, author, or location is unknown [Lesk, 1979]. IBM's STAIRS, developed for their recent antitrust suit and subsequently marketed commercially, is also used to build such inverted files with a much larger database [IBM, 1979]. As advances in AI language understanding are made, the system might take on a more significant role in classifying material by the concepts, rather than just the words, that it contains.

Vital areas for research include the development of automatic indexing facilities and a means by which the system may engage in dialog with the user to help determine and satisfy his or her retrieval requests. Both of these areas require that the system understand either the document or the user to produce the best solutions. Consequently, our initial research will concern itself with the simple indexing and classification schemes discussed above and the creation of retrieval dialogs using words and gestures that do not require research in language comprehension.

3.1.3.8 Annotation

In one electronics shop onboard the U.S.S. Independence we observed technical manuals that had been extensively annotated in color with additional text and drawings. These annotations were strongly done by the technicians while in school, and later during actual repair activities. Thus, the manuals had become a personal respository of maintenance and repair experience. The wish was expressed to us that all technical manuals could be so annotated, not just personal copies of training manuals obtained in school. Our observations were strongly reinforced by the NTIPP Fleet Survey of Technical Manual Users [Hughes, 1978]:

> It can be noted here that the primary advantage seen by [technicians] in having their own set of manuals is the ability to personalize them by adding marginal notes and supplemental data. The primary disadvantage cited was the added burden of having to maintain their manuals in an up-to-date condition. Approximately 53% of the overall sample felt that having to update the manuals would be bothersome. . . .
>
> In addition to the technical manuals, it was noted that at least some of the materials obtained in training, as well as their own supplemental material, are required in the performance of their job. This is predominantly the case for both technicians and operators.

The provision of quick update facilities (the lack of which is the primary disadvantage of having one's own personal, personalizable documentation) is a key goal of the future system.

Annotation may not be looked upon favorably by those who produce the manuals, some of whom feel that annotation is often an unsatisfactory subsititute for reporting unclear or incorrect material and that it could be obviated by writing correct, up-to-date manuals [Shihda, 1979]. We believe, however, that no documentation, no matter how well crafted, can be all things to all people. Annotation capability should be offered if it can help clarify material for one reader when it is already more than adequately clear for most, if it can be provided without affecting the way other users see a document, and if it is accompanied by easy-to-use facilities for reporting actual documentation problems.

How may autographed user annotations be associated with a technical documentation database? The sort of annotation facilities required depend on the application. An inquiry needs to be made into the kinds of annotation techniques currently employed in a cross-section of communities and disciplines. What do potential users find essential, desirable, or lacking in their present tools?

Though bitmapped annotations (uninterpreted graphics input by the user and overlaid on the displayed document) provide for the most freedom in marking up a document, an alternative approach could employ a small, user-defined set of annotation primitives (e.g., circles, boxes, and underscores of various colors), perhaps indicated to the system by appropriately gesturing at the display or data tablet [Applicon, 1979]. Such annotations might be compactly encoded and intimately associated with the information to which they refer. Retrieval requests based on the user's annotations would then be possible. For example, the user could instruct the system to display all information circled in blue. Or annotations might be automatically created by the system when the user requests that all occurrences of a specific part name be circled.

Our experience with FRESS has shown that users should not only be able to mark up a personal copy in a smooth and natural fashion, but should be able to easily compile a digest of selected information for fast retrieval by copying relevant sections to a common workspace, and ordering/annotating them to suit.

User annotations ideally should be dynamically propagated (if desired) when a document is updated. This is to say that annotations should be associated with the information in the database and not merely with its appearance on the display screen. If the system stores an annotation with the section annotated, then intervening material may be edited without invalidating the annotation. A simple bitmapped overlay scheme does not handle this problem. If words are shuffled about, on or between pages, the overlay will be "off register" — the annotations and the annotated material will no longer be properly aligned. This problem is very difficult in the general case, corresponding to that of tracking editing changes in a manuscript, considered by the Hypertext group at Brown [Elliott, 1971a]. It is unclear how to display annotated material that is itself split during update and moved in pieces to different parts of the document.

Our initial efforts will concentrate on developing effective annotation techniques requiring no semantic analysis of annotations or annotated text, some minimal pattern recognition of basic gestures made by the annotator, and experimentation with means of associating annotations with specific information in the database, as opposed to the use of simple bitmap overlays.

Future research might investigate the possibilities of applying artificial intelligence techniques to the extremely difficult problem of propagating updates when the wording of an annotated section changes.

In addition, we would like to eventually consider the feasibility of checking annotations for consistency and accuracy:

- If the system is taught that, for example, only certain types of data may be circled in red it should notify a user who attempts to misplace a red circle. An "annotation key" display could show the user-defined meaning of each annotation primitive.

- If verbal annotations are interpreted by the system as words, rather than meaningless (except to the annotator) marks to be displayed, then artificial intelligence techniques might be applied to their content to provide some rudimentary test of their accuracy.

3.1.3.9 Personalized Presentation

How can the documentation system alter its presentation to suit the perceived abilities and skills of its user? By analyzing the user's responses, the system might determine, without being explicitly told, default browsing speed, preferred presentation level of detail, proportion of pictorial to verbal material displayed, and even the complexity of information which the user is able to handle. Such a system will not only obey, but infer, as well.

How will users react to a machine that is seen as a "Big Brother"? Probably with little enthusiasm. The user's suspicions and fears about such a powerful tool must be considered in its design philosophy. The system must be configured and introduced as a personable, as well as personalized, assistant, modifying its own behavior to that of the user, instead of forcing the user to conform to it.

Much work has already been done at MIT towards the development of a system that produces personalized movies for use as maintenance and repair instructional aids [Negroponte, 1978; Mayer, 1979]. A changing model of the user helps determine the selection of material from a database of static and dynamic, sound-synchronized images. A movie tailored to the abilities and display preferences of the user is generated "on the fly"; its mode of presentation and level of detail may be altered by the user at any time.

Fruitful and extremely difficult areas for research include not only the analysis of the user's responses, but as well the development of means for providing different forms of the same information (e.g., pictorial vs. textual). Must the information be redundantly encoded, as in the MIT system, or could a single common encoding suffice? Spatial data, such as a printed circuit board layout, might be presented to the user as either a verbal description or a line drawing by processing the same stored data structure differently. A common database might be developed using the knowledge representation techniques that are currently the object of research in artificial intelligence [Charniak, 1976; Goldman, 1975].

3.1.4 FUTURE SYSTEM: GENERAL RESEARCH PROBLEMS

3.1.4.1 Authoring

New documentation formats with complex structural information and dynamic displays will require a radically different approach to authoring. Sophisticated software tools will have to be employed to structure the database and create dynamic sequences. The delivered documentation might well incorporate material produced by the vendor's own computerized design and documentation system.

Section 3.1.3 described several interaction capabilities that transcend those currently available with conventional technical documentation media. In order to make full use of sophisticated travelling, structure, and presentation techniques, documentation must be prepared specifically for the new medium. If, for example, an existing technical manual were simply copied, transferring existing text, pictures, and structure, the net result would be a duplicated database, with little or no increase in capabilities. For example, microform conversion programs such as MIARS advocated the simple photoreduction of existing manuals. While bulk was decreased, no new interaction capabilities were gained. Instead, some, like annotation, were lost. Even in programs which introduced new manual formats without changing medium, such as JPA, success depended on developing new writing skills which took advantage of the format [Chenzoff, 1973].

Authors must be trained to "write" effectively for the new medium, and tools, such as "authoring languages", must be developed to aid in this intellectually demanding process. Even with such tools, authoring will be a difficult, time consuming, and therefore costly task. The problems encountered in creating "courseware" or lessons for the University of Illinois PLATO computer aided instruction system are well known [Sugarman, 1978]. At Brown University, the development of a highly structured database for instructional use in college courses proved to be a major intellectual task, demanding creativity, thoroughness, and the ability to visualize and impose complex structure by hand [Strandberg, 1976]. These problems were faced in a database primarily limited to text; the introduction of static pictures, let alone animations, complicates matters considerably.

In order to make possible the production of large amounts of new documentation, powerful computer based tools must be developed. Such tools might be superset extensions of the documentation delivery system or totally independent of it. They must provide facilities for:

- inputting and editing text and (dynamic) graphics,
- imposing structure on the documentation,
- developing procedural troubleshooting and training sequences,
- propagating updates (checking consistency and completeness) and doing version management, and
- incorporating end user feedback.

Fundamental research must be done to determine the kinds of authoring tools needed, as well developing effective means for structuring multimedia information. A beginning can be found in the work done in such fields as Computer Aided Instruction (CAI), Computer Aided Design (CAD), technical animation, film, television, and text processing.

3.1.4.2 Integration

Can information peculiar to a particular piece of equipment (its repair history) be compiled and catalogued by serial number for access by the technician? Such information, when in machine-readable format, can be automatically analyzed to discover patterns of malfunction, useful for correcting possible design flaws and predicting needed parts stocks.

How can the functionality needed to provide ready access to documentation also be used to:

- request materials needed for maintenance and repair, interface with automated stockroom systems, and record access to local pre-expended bins. The user might indicate the needed part to the system which would automatically report on its whereabouts and, if necessary, requisition it. The need to know about (and look up) ordering information would be eliminated, and valuable time would no longer be lost filling out forms.

- report on the status of equipment under repair -- automatically monitoring information vital for readiness, and repair scheduling.

- enable the technician to offer feedback on undocumented equipment problems, repair techniques, and technical documentation shortcomings.

- capture utilization statistics useful in determining technician effectiveness and assisting with accurate scheduling.

3.1.4.3 Retrofit of Existing Documentation

One of the most difficult logistical aspects of developing a new technical documentation medium is the problem of creating a highly structured database. Because of the number of technical manuals that are currently in existence, and the rate at which this information grows, the electronic capture and conversion of this old data to the new medium presents a tremendous "retrofit" problem, separate from the task of creating completely new documentation especially for the new medium.

The magnitude of the retrofit problem becomes apparent when two factors are considered. First, existing documentation must be rewritten to some extent to take advantage of more sophisticated graphics capabilities (including animation) and restructured for new access methods. Existing redundancies should be removed. Second, the large number of existing technical manuals (see Appendix A.2.3) would make a rewrite of all of them prohibitively expensive. The alternative, simple conversion without rewriting for the new medium, only duplicates the existing documentation without any advantages other than the potential for rapid update propagation.

An indication of the difficulty and cost of both retrofit strategies (simple media transfer and rewrite) can be seen in previous efforts at introducing new manual formats (e.g., those for JPA and FOMM, discussed in Appendix A.2.1.1), and new documentation policy programs such as NTIPP. In these programs it was decided, because of high conversion costs, that the new formats would primarily be introduced in new technical manuals, rather than in rewrites of old documentation. However, some selected manuals were experimentally rewritten during program development.

Given the 10-15 year time frame for the development of this new medium, the amount of author and user training that will be required for it to gain acceptance, and the difficulty of the "conversion" problem, it is likely that a comprehensive retrofit strategy cannot be adopted. Rather, like the new manual format and policy programs discussed in Appendix A.2.1.1, there will be a gradual process of developing new documentation for new equipment and some selective rewriting of a few potentially long-lived or high priority technical manual sets. Thus, it is unrealistic to assume that any new automated medium will displace paper in the near future.

3.1.5 TECHNOLOGY ESTIMATE

In order to develop a computer based technical documentation system with the characteristics we have defined, advanced technology will be needed. In this section, we shall look at these technology requirements, and estimate the resources required: processing power, storage, and graphics hardware. This estimate is intended only as a rough guide and is made using current technology and recent technology estimates as a point of departure.

3.1.5.1 Processing

The physical compactness of the future system mandates the use of microprocessors for local processing. The tasks which they must perform include:

- command processing and executive control,
- input device handling,
- data access from secondary storage,
- data communication with remote databases or processors, and
- graphics display processing.

The interrelationship of these tasks is shown in Figure 1. Note that each functional division may require one or more processors to achieve the necessary speeds for fast data access and display. Each of these functions is described below.

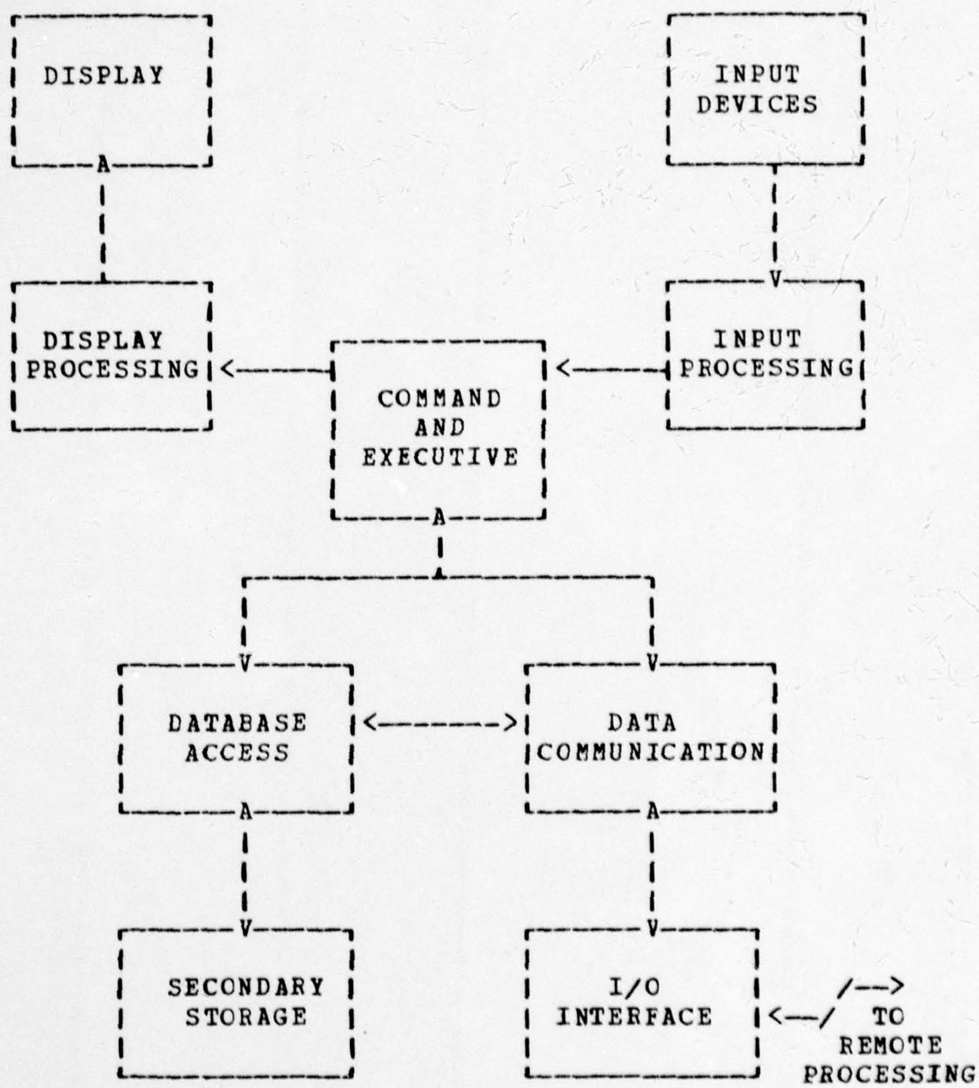

Figure 1: A Technical Documentation System Process Layout

• Command and Executive

This function includes central control of the other system functions through an operating system, and the processing of user commands. The processing power needed is not that great (it could be handled by currently available microprocessors). The biggest problem in this area is interprocessor communication. With such a distributed architecture, a sophisticated interface and coordination strategy must be developed.

• Input Handler

The low-level handling of the input devices is included in this function. In addition, more sophisticated input processing, such as text editing, voice and handwriting recognition, and pick correlation would be done here. It is important that input be kept as simple and familiar to the technician as possible (e.g., handwriting, finger pointing, voice). Depending on the level of the input processing, these functions might share the command and executive processor. On the other hand, more sophisticated forms of input, such as voice, would require a separate high-speed processor.

• Database Access

The access of desired information from the database consists of two tasks: deciding what data is needed to satisfy the request, and transforming it from the format in which it is stored into a suitable display format. The data structures required for display are typically very different from those needed for information storage and retrieval. Significant processing is needed for quick transformation between the two representations. Retrieval might require the application of artificial intelligence techniques if inference making for processing "high level" queries or achieving personalization is to be done. Otherwise, standard information retrieval techniques could be used. In either case, the internal database structure must allow for quick retrieval.

The speed and data requirements for this function are high. Typical random access time for a display frame should be no more than 1-2 seconds, on the average. Depending on the level of encoding of the data, this processor must be capable of transferring between 5K bytes (character encoded text page) and 1M bytes (1Kx1Kx8 unencoded raster page) in that amount of time. For consecutive frames of a sequence or an animation, the access time must be considerably less than one second. One solution to this problem is local buffering or pre-fetching of a number of pages or frames at once, in a "working set" strategy for displaying related pages of information. This reduces processor demand somewhat, but increases local primary storage requirements, which are not forseen to be a problem with future memory technology.

• Data Communication

This function provides data transfer from an I/O interface to a remote database or processor, such as a central technical library. The strategy for this type of access would be to make requests of the database, and receive several pages of technical documentation data to be buffered in local storage for later processing and display. For example, in the Work Package concept (see Appendix A.2.1.1), fewer than 30 pages of information would be required at any time. To access this amount of data in a reasonable amount of time, a high speed data link would be required. A 1Mbaud rate over coaxial cable is easily possible between points on a ship. The data rates mentioned for database access also apply here.

Problems potentially arise when animations are used. In the worst case, successive unencoded frames of raster data might be transmitted, requiring a 30 Mbyte/sec rate for 1Kx1Kx8 bit frames. However, already existing encoding schemes make it unlikely that speeds of this magnitude will be necessary.

• Graphics Display Processing

Graphics presents the highest processing speed demands of any of the functions in the system. The display technology chosen might initially be raster graphics based (see Section 3.1.5.3). Thus, displays in their most basic form would consist of bit mapped data. The resolutions necessary for legible, high content displays require on the order of 1 Mbyte of storage. For dynamics (such as animation), the worst case would be rewrite of the entire data 30 times per second, resulting in the need for processing throughput of up to 30M bytes/second. Currently, the fastest available microprocessors operate at speeds approaching 1 mips (million instructions per second). It is estimated that to support the type of dynamic graphics needed for animations, 10-100 mips processors will be needed [Kay, 1977]. It is not unreasonable to assume, given current trends in VLSI technology development [Torrero, 1979], that microprocessors will be able to achieve these speeds within ten years. In addition, there are several factors which mitigate the speed and storage requirements:

- Encoding of graphics data reduces the size figure. Text, for example, is typically encoded in 8-bit bytes. A page of text containing 60 lines, each 80 characters long, requires only about 5K bytes. Techniques such as run-length encoding (for data compression) and scan conversion (encoding of bit-per-pixel raster data in strokes stored as X,Y coordinate pairs, one for each endpoint) also reduce the amount of data to be processed. However, encoding alters the processing distribution from simple data movement to more sophisticated encoding/decoding tasks. Specialized fast processors, built using custom VLSI, could be dedicated to these operations.

- Dynamics do not usually require the processing of the entire picture bit map. Techniques are available to isolate the dynamic from the static data, to reduce the amount of data to be processed in each refresh cycle.

- Graphics processing lends itself to parallelism. Several microprocessors working in parallel (one for each plane of raster data, for example), can share the load.

- A large part of the data to be displayed is static, and requires less processing.

3.1.5.2 Storage

There are several requirements for storage technology in the technical documentation system. A high capacity, rugged, cheap, removable secondary storage medium is necessary for holding technical documentation databases. This would enable a technician to obtain all documentation on equipment that he is servicing in one, easy to use form. In addition to secondary storage, the technical documentation system would require large amounts of high speed primary memory for buffering of technical documentation data pages and display refresh.

• Optical Disk

Optical disk technology, which is just starting to become generally available, seems like an ideal candidate to fill this need. Optical disk technology has been used for video and digital data.

Current videodisks are capable of storing 54K tracks of 1M bits/track. A typical disk has an average access time of 2.5 seconds per frame, with a worst case access time of 5 seconds (first frame to last) [MCA, 1979]. Videodisk systems have facilities for indexed retrieval of individual tracks on a random access basis, as well as continuous sequences of frames for a television picture (up to 30 minutes per side).

As attractive as the videodisk is, there are several problems with current implementations:

- They are read only. However, direct read after write and read-write capability is in the research stages [Kenney, 1979].

- They require a fairly sensitive playing device which rotates the disk at high speed (1800 rpm). This presents portability and ruggedizing problems.

- Indexing (random access) schemes need development. There is currently no way of combining the continuous and indexed access modes.

Optical disks designed as a replacement for random access magnetic disk storage of digital data are under development. For example, an optical disk system being developed by Philips Research Laboratories has a capacity of 10 billion bits on a 30 cm disk with a mean access time of 70 ms, a recording rate of 10 Mbits/sec, and an error rate of between 10^{-5} and 10^{-6} bits. This system uses laser recording and playback technology, a tellerium disk medium, and rotates at approximately 1200 rpm [Bulthuis, 1979].

Within the next few years, it can be expected that the problems of read/write optical video and digital data disks will be solved. Philips predicts that a 25 ms average access time for optical data disks (comparable to good magnetic disks) is achievable with capacities of up to 100 billion bits.

• Local Storage

Primary memory is distributed in several places throughout the technical documentation system. The need for buffer memory for a number of pages of technical documentation data has already been mentioned. This will require fast access storage in the 3-5M byte range. In addition to this, refresh memory for the graphic display will require another 1M byte, unless the development of flat panel displays with integral memory obviates the need for separate refresh memory. The requirement for this much memory in a portable device is a stringent one. However, advances in semiconductor and magnetic bubble memories in the next ten years will probably make this possible [Hodges, 1977]. Some current microprocessors can already access this large an amount of memory.

3.1.5.3 Graphics

We have already mentioned the use of raster graphics display technology. Raster displays currently have the ability to display high resolution, color pictures without flicker. Dynamics are limited (as opposed to those obtainable with stroked or vector displays), because of the processing needed to handle the large amounts of data required at high speeds.

Current color display resolutions range up to 1280x960x16 (elements x lines x bit planes). Naturally, the greater the resolution of the display, the more legible it is. For purposes of a technical documentation system, where large amounts of text and graphics must be displayed, 1Kx1Kx8 or better resolution would be good. The amount of text that can be displayed also depends on this resolution. For example, characters may be defined in a 7x9 pixel matrix, with 9x12 pixel spacing, allowing approx. 80 lines of 110 characters on a 1Kx1K display, though, to insure maximum legibility, not all of these would be used.

Current raster displays use high resolution color CRT monitors. In order to meet the portability and durability requirments for the technical documentation system, a high resolution, color, flat panel display must be developed. Work is being done with thin and thick film semiconductor technology to achieve this [Tannas, 1978]. However, this seems to present one of the biggest technological challenges in the development of a rugged, portable system.

Another requirement for a technical documentation system is a touch sensitive input device that is integral with a flat panel display, and has enough resolution, accuracy and durability to be used as a picking and input device in a shipboard environment. Touch sensitive input devices with sufficient resolution and accuracy are already commercially available from Elographics and TSD Display Products.

3.1.5.4 Sizing Estimate

An estimate of the processing and storage resources needed in a computer based technical documentation delivery tool can be derived from the amount of data to be handled in some typical documentation data bases. The size of the standard, text oriented documentation for existing military equipment varies. For example, the documentation for a small system, the AN/VRC-12 series radios examined in [Gurwitz, 1978], is contained in 6 volumes of approximately 1200 pages. On the other hand, the documentation for an entire helicopter (the UH-1H) consists of approximate 9200 pages in 38 volumes. An intermediate-sized example is the documentation for the J-85 jet engine: 5500 pages in 23 volumes [Chenzoff, 1973].

With these figures in mind, the capacity of a hypothetical technical documentation delivery system can be estimated. For the purposes of this rough estimate, a one-to-one correspondence can be drawn between manual pages and "frames" in a technical documentation system (see Section 3.1.3.2). This assumption makes for a conservative estimate, since the computer based system would not have to have the physical repetition of figures within a manual and redundancy between different volumes in a set of manuals. For example, JPAs employ many more pictures than traditional technical manuals, but their rate of reuse within a manual is much higher [Chenzoff, 1973]. The future system could reuse figures and other material by storing one physical copy and referencing it as needed. Conversely, if animations are used, the amount of information needed may expand significantly.

In totally unencoded format (e.g., a raster bitmap representation where manual pages are stored in digital facsimile form), the storage needed for a manual page is 1M byte, for a high resolution display (1Kx1Kx8 raster). This can be taken as an upper bound, since encoding schemes such as run length encoding (for pure data compression), vectorization (for representing line drawings using scan conversion), and character encoding (for text), will most likely be used. These and other schemes, used singly or in combination, reduce the 1M byte/frame figure tremendously.

Using current estimates for optical disk technology as a model, about 750 of these unencoded frames could be stored on one side of a 14 cm disk (1M bit/sector or 8 sectors/frame) [Bulthuis, 1979]. The overhead required for control information needed for indexing and structuring the frames should be less than 20% of the storage space (in the system proposed in [Gurwitz, 1978] it was less than 10%). Thus, the equivalent of about four manual volumes could be stored on one side of a disk, with access times and processing requirements as described in Section 3.1.5.1. However, Philips is currently developing a 30 cm disk with ten times the capacity of the 14 cm prototype. With advances in optical disk or other storage technology, encoding schemes, and rewrite of existing documentation to take proper advantage of the new medium, this figure would increase.

3.1.6 SUMMARY

As has been argued in Section 3.1.5, there are many difficult technological problems that must be solved before an effective technical documentation system can be implemented. While some of these problems seem amenable to solution by extrapolating current trends in technology, it is not clear that all of them can be solved adequately within ten years. One must also take into consideration the cost and reliability of such a tool, even if all the design and implementation problems are solved.

Technological considerations aside, more important basic research must be done in the fundamental and potentially more difficult areas discussed (interaction methods, data representation, internal and external database structure, etc.) if such a tool is to be available within ten to fifteen years. Both the technological and information problems must be worked on concurrently if a computer based system is to be a solution to technical documentation problems in maintenance and repair. Thus, our proposed strategy of developing technical documentation techniques on available interim equipment in a testbed facility seems desirable.

We can summarize the areas where research is needed to achieve the goal of a computer based technical documentation system, as we have described it. The problems fall into several (partially overlapping) categories:

<u>Information Problems</u>

These are problems which can be solved by the development of "soft technology": algorithms and software systems, in such areas as AI, graphics, and databases. These require new methods of applying existing technology, and adapting and refining techniques:

- structuring a technical documentation database for flexible and efficient user access,
- representing information, both for fast system retrieval and for display,
- making the system "user friendly" and easy to learn; providing practical "help" facilities,
- developing mechanisms for creating and viewing annotations,
- presenting technical documentation data effectively on a small display,

- creating and maintaining large, highly structured databases, and

- providing feedback between direct maintenance and repair activity and administrative functions (scheduling, inventory, quality control and assurance).

Technological Problems

These call for the development of entirely new "hard technology" or the improvement of currently existing applications (i.e., the development of faster processors and larger memories). We need:

- powerful microprocessors and/or VLSI chips for fast data transfer and dynamic graphics,

- large amounts (many Mbytes) of fast primary storage in a portable device,

- rugged, random access, read/write removable media (possibly optical disk) for mass secondary storage,

- flat panel, high resolution, color displays with an integral touch sensitive input device,

- effective input devices that are both simple to use and powerful enough for sophisticated interaction (e.g., handwriting and voice), and

- devices which can withstand hostile environments and be made "sailor proof".

Problems of Understanding

These are problems which require research into fundamental concepts. They are not well understood and it is not clear that solutions to all of them can be found in the next ten to fifteen years. Fundamental problems include:

- retention of as many useful capabilities available with paper documentation as possible,

- development of interaction modes which support integrated design, training, and maintenance and repair (see Section 3.2),

- personalization of the system for individual user skills and interaction preferences,

- development of authoring tools and methodologies for multimedia presentations, and

- development of animation techniques, starting with the comparatively easy 2 and 2 1/2-dimensional symbolic domains and eventually including 3-dimensional mechanisms.

Social and Economic Problems

This set of problems consists of general ones which affect the success of a new medium if it can be introduced. They must be considered when dealing with any of the others. The system must:

- be cost-effective,
- be accepted by technicians and managerial personnel, and
- allow a sensible retrofit strategy for adapting existing documentation to the new medium.

Our interests lie with researching those information problems that require new application and development of soft technology: structuring of multimedia databases, presentation techniques (including animation), development of new interaction methods, annotation, and personalization.

3.2 Relationship of Design, Training, and Maintenance

One issue that surfaced throughout our study, was the fact that there exists some relationship between maintenance and repair and the areas of design and training. The existence of this relationship affects the scope and purpose of a computer based technical documentation medium. Rather than just providing a reference source for maintenance technicians, a computer based technical documentation system of the future could also offer integral training and possibly even equipment design facilities.

The data for these disciplines are very much interrelated. It has been said that maintenance is a consequence of design [Blanchard, 1969]. From the perspective of system life cycle, the influence of design on maintenance, and of both design and maintenance on training are clearly evident. The data needed for maintenance and repair results from the data produced in the design task; e.g., the engineering drawings (schematics, blueprints, or block diagrams) that result from the design process are crucial to maintenance and repair. Training data is also related to design and maintenance data, since support training often consists of hypothetical maintenance problems and operating training is based on documentation (user's guides) that are a direct consequence of design. In electronics, for example, a technician is trained to repair a specific piece of equipment and often uses the technical manuals he or she received at school as a primary reference source when performing maintenance and repair [Hughes, 1978].

Finally, maintenance and repair data can affect training and design. The results of failure analysis can be fed back into the training process, influencing the development of new maintenance procedures and training methods. This data can also affect the redesign of equipment for more reliable operation.

3.2.1 UNIFIED DEVELOPMENT PIPELINE

One indication of the importance of the relationship has been the emergence of system development strategies that emphasize unification of the three disciplines. These approaches are given different names, based on the functions they affect. Integrated Logistics Support (ILS) is a management function that stresses the consideration of system's support in all phases of the system life cycle. The Integrated Systems Concept makes field operations considerations a guiding force in the conceptual design of technical systems. The Integrated Data Concept stresses the total identification, development, and control of all technical data as an integral part of a system design and development effort [Walton, 1965]. These concepts are all accepted by the military, as evidenced by programs which specify that the production of training and maintenance documentation be integrated with systems design and development [Folley, 1978].

Some advantages of an integrated approach are:

- development of more reliable technical documentation leading to reduced cost,
- avoidance of duplication of effort in documenting systems,
- reduced data conflicts,
- centralized control of information, and
- increased accuracy and timeliness of information.

3.2.2 INFORMATION TYPES

In addition to the integration concepts described above, there are commonalities between the information types found in the disciplines of design, maintenance and repair, and training which merit further investigation. The results of the design process include engineering drawings, operating instructions, functional specifications, preventive maintenance, calibration, and special repair requirements. Maintenance and repair documentation is developed from this information and a maintenance analysis, which identifies human interfaces and logic for system checkout and troubleshooting. This documentation is comprised of technical manuals which include much of the information generated from the design process, as well as troubleshooting procedures, and disassembly, repair, and replacement instructions. Training documentation will often make use of technical manuals for maintenance and repair, as well as specially developed training procedures which include student test questions and example problems. One survey showed that over 75% of Navy technicians used technical manuals in their courses [Hughes, 1978].

Thus, the data for each discipline is invariably related to the others, with maintenance and repair and training data being developed from design data. However, their organization and format differ significantly. For design data to be useful later in the development life cycle, it must be organized into a standard format that is usually very different from that generated during the design process. Design data is less formal and not structured for information retrieval by maintenance task. Another important difference is revealed when modes of user access are considered.

3.2.3 INTERACTION CHARACTERISTICS AND PRESENTATION METHODS

The human interface differs for design, training, and maintenance and repair data.

Design is an active, creative process that involves tradeoffs between conflicting design constraints. Design data may start out as very rough informal drawings which are continuously refined in an iterative manner, until the final design is achieved. During this revision process, the design may change radically as unexpected conditions arise and optimizations are discovered. The design process continues during development: rough sketches are formalized, maintenance requirements are developed through analysis, and a production strategy is arrived at.

Training is also an active process. For learning to take place, there must be interaction between the teacher and the student. This interaction can take the form of teacher/student questioning as well as practice questions or laboratory exercises. When students become passive readers of training manuals or passive attendees at a lecture, training can lose its effectiveness.

Finally, corrective maintenance and repair is a highly interactive activity that also requires a certain type of creativity. In many instances in troubleshooting, the availability of certain information at the right time can lead the experienced technician to the realization of the cause of a problem. Proceduralization of the process can reduce the amount of creativity required from the technician [Elliott, 1971]. There exist differences of opinion on the merits of troubleshooting techniques that emphasize highly specific procedures rather than theory [Shimberg, 1969; Kruvand, 1970]. Procedures that specify every step needed to isolate and repair a fault enable personnel with little training to maintain equipment. However, procedures of this type (such as those found in the FPTA or maintenance dependency charts discussed in Appendix A.2.1.1) are currently expensive to produce, may be usable only by highly trained and experienced personnel, incur a considerable cost of time, and may not cover all types of failures [Frazier, 1979]. When a maintenance and repair procedure is incomplete or fails to uncover the fault, the poorly trained technician is at an impasse. A technician trained in the theory of operation of the equipment can often use his or her skills to succeed where a fault isolation procedure fails. However, this assumes a highly trained technician with troubleshooting skills -- someone that may be scarce in the military of the future.

The merits of proceduralization versus theoretical background need to be studied further. The results of these analyses will have great impact on the shape of a future technical documentation system. If the percentage of cases where proceduralization is adequate is high compared to those which require theory training, then a centralized "help" facility that makes expert guidance available to the technician through the system could be created. For example, the expert resource could instruct the technician to take specific measurements and offer guidance should standard maintenance procedures fail. A basis for such a facility can be found in several online, interactive consulting facilities currently in use on computer systems (e.g, PLATO, NLS).

Training and troubleshooting (fault isolation) are similar, in that troubleshooting requires the technician to "learn" (or re-learn) the operation of the equipment under repair in order to be successful. This understanding process may come from the same or similar documentation that is used for training. On the other hand, training exercises may require the student to perform practice troubleshooting exercises to reinforce his or her knowledge of the equipment.

3.2.4 SUMMARY

We have argued that there is a very close relationship between maintenance and repair, training, and design. The advantages of an integrated approach toward development of data for these three areas have been described. Further research into the relationship between these areas is necessary. Such work in understanding commonalities in data and interaction modes will result in the more efficient development of technical documentation, and in its better utilization.

APPENDIX A : CURRENT NAVAL TECHNICAL DOCUMENTATION FOR MAINTENANCE AND REPAIR

As a result of our investigations, we have partitioned our discussion of technical documentation for shipboard maintenance and repair into two general areas: direct maintenance and repair support, and technical documentation technology.

- Direct maintenance and repair support relates to the actual performance of maintenance activities by the technician: what is done to solve a maintenance problem, how it is done, and what information is needed to do it. This area also deals with the peripheral activities of material and workflow management. By looking at this general area, we can gain insight into the user's needs and requirements for technical documentation.

- Technical documentation technology encompasses the systems required to deliver technical documentation to the technician, from their planning to their operational use. It also encompasses the design of the documents themselves. Our purpose in examining technical documentation from this point of view is to identify problems, both existing and potential, in supporting and managing technical documentation.

In both of these areas, we shall examine the processes involved and try to characterize them as "pipelines" of connected processes. This model will be used to identify the data that is used, and isolate potential problem areas or "bottlenecks." In addition, we shall try to estimate the amount of data generated and consumed in each component activity in order to determine the applicability of automated solutions.

A.1 Direct Maintenance and Repair Support

A.1.1 TYPES OF MAINTENANCE AND REPAIR

Maintenance activities can be divided into two categories: preventive and corrective.

Preventive maintenance activities are regularly scheduled, well defined procedures that can be summarized in proceduralized sequence documents (step by step instructions and checklists), such as work packages or cards [Walton, 1965]. Activities that fall into this category include:

- Visual inspection
- Checkouts
- Servicing (cleaning and lubrication)
- Scheduled replacement of time significant parts
- Calibration and alignment

Programs for preventive maintenance are usually developed during pre-production planning from system development data that results from the design process. The biggest problems involved are in analyzing the design data to identify where preventive maintenance is required, while avoiding possible over-inspection that can result in greater equipment failures by accident or through a technician's incompetence.

Corrective maintenance, on the other hand, is a much less well specified and organized set of activities. While troubleshooting checklists and action trees (decision trees with actions associated with each node) are often used for diagnosis, procedures and data for this type of maintenance and repair typically cannot be adequately planned in advance. The technician is left to rely on his or her own experience and expertise to interpret the available data in order to isolate and repair a fault. Consequently, the provision of the necessary data in a form that the individual technician is most comfortable with should be one goal of technical documentation. Technical manuals are the traditional technical documentation used in corrective maintenance.

There are three levels of corrective maintenance support to be considered: organizational, intermediate, and depot level. These levels comprise a maintenance and repair hierarchy, with organizational support as the lowest (most direct) level.

Organizational support is performed on the level of the individual department within a ship. It is usually the responsibility of the unit that operates the equipment and includes the least detailed type of work: minor adjustments, and localization of problems to a modular level where repair involves simple module replacement. Organizational maintenance documentation is often included with operating instructions.

Intermediate support, the next level up, is more extensive and usually involves repair at a lower level of modularity (e.g., the circuit board level in electronic equipment). Intermediate maintenance is performed by an organization comprised of specially trained technicians, whose sole task is maintenance.

In the case of the tender we visited, an entire ship was devoted to intermediate maintenance. On the aircraft carrier, there were departments within the ship for it. The documentation on this level is more detailed than that for organizational maintenance, and is found in separate manuals.

Depot level support is the most complete and extensive level of maintenance. On this level facilities exist for the total overhaul of equipment. It is primarily land based and not directly involved in support of active equipment.

On each level (except for the total reconditioning of equipment), the activities of corrective maintenance are similar: these are the steps that the individual technician goes through to identify and repair a fault. Each step involves data which the technician needs to perform his or her task. This process has been analyzed extensively in the field of maintainability engineering. One such task breakdown consists of the following phases [Blanchard, 1969]:

- preparation (includes gathering of tools and setup of test equipment),
- localization (using no external test equipment; observation only),
- isolation (using external test equipment),
- disassembly,
- interchange,
- reassembly,
- alignment, and
- checkout and verification.

The degree of difficulty of any phase depends on the type of equipment being serviced and the circumstances surrounding the problem. For example, an intermittent fault makes isolation more difficult because of its dynamically changing nature. Thus, to determine the problem areas in this model of maintenance and repair, we must first distinguish between the various classes of equipment to be repaired, the environments in which they are typically found, and the type of technical documentation that exists to support them.

A.1.2 SHIPBOARD ORGANIZATION OF MAINTENANCE AREAS

Figure 2 is a diagram of the organization of the U.S.S. Puget Sound, which gives a good idea of the range of Naval maintenance and repair. Note that a similar range was found on the carrier, though further complicated by the special needs of providing maintenance support for aircraft, which accounts for a large segment of its maintenance organization. As shown, the major divisions of the maintenance areas are:

- Hull: structural repair, painting, welding, and foundry work.
- Machinery: fabrication of machined parts, valve, boiler, and pump repair.
- Electrical: motor and gyroscope repair.
- Electronics: communications equipment, radar, test equipment repair, and electronic calibration.
- Ordnance: small mechanical repairs, fire control, gun, and launcher repair, and mechanical instrument calibration.

Other departments are responsible for administration (workflow and parts management, planning and estimating, and accounting), quality control and assurance, and nuclear propulsion repair. Each department is divided into divisions responsible for a particular sub-area (e.g., valves in the machinery department); each division is comprised of work centers which are clusters of technicians, under the command of a supervisor, who are responsible for particular equipment.

These maintenance areas can be roughly divided into two categories: mechanical and electronic. Several areas, such as electrical and ordnance, share features of both.

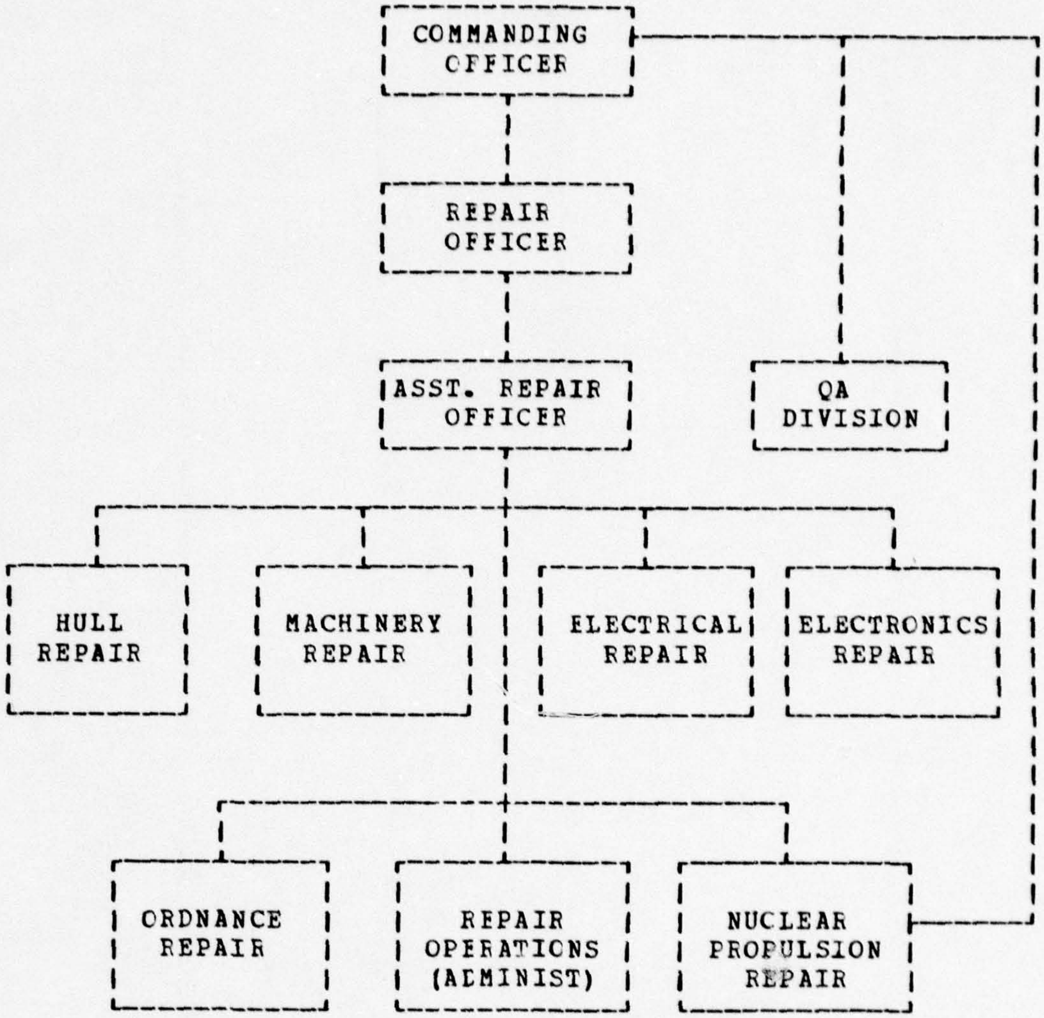

Figure 2: U.S.S. Puget Sound Organization

A.1.2.1 Mechanical

Maintenance and repair activities for mechanical systems (e.g., hull and machinery) are less oriented toward localization and isolation, and place more emphasis on the disassembly, interchange, and reassembly phases of the pipeline, since faults in these systems are usually obvious upon visual inspection. Two factors often complicate the repair of mechanical systems: the large physical size of many of the items to be serviced, some of which weigh many tons, and the need to fabricate replacement parts. The latter requirement results from the age of many ships (some more than twenty years old), which makes finding replacement parts impossible at times, since suppliers may no longer exist. In some cases, such as hull repair, no replacement parts were ever contemplated (e.g., repair of a cracked bulkhead). As a result, much of the resources of mechanical departments are devoted to fabrication: foundry, welders, etc. A third complicating factor in this area is environment. Much repair must be done on-site, in hostile working conditions.

Technical documentation consists mainly of 2-D blueprints (hull), 3-D isometric parts explosions and 2-D planar views (machinery), and disassembly and maintenance procedures for mechanical assemblages, such as pumps. Blueprints are the preferred form of documentation for mechanical technicians [Hughes, 1978]. The availability of documentation in mechanical areas, especially hull, is low. The reasons for this include the age of many mechanical systems in use and lack of criticality. In areas like machinery (pump or boiler repair), where maintenance and repair procedures are needed, formal documentation is sometimes available. However in areas such as structural repair, blueprints may be the only documentation available, since other documentation is unnecessary. In cases where fabrication is required (making machined parts, for example), informal drawings may be made from measurements of old parts, rather than from blueprints on file. However, the need to take precise measurements of parts whose blueprints are unavailable, for example, does result in a loss of the technician's time.

A.1.2.2 Electronics

Electronics presents a much different set of requirements than the mechanical areas. Repair is largely oriented toward localization and isolation. Test equipment is necessary, since visual inspection alone is not adequate for fault isolation. One estimate is that fault identification takes up 60% of the effort in repair of electronic systems [Blanchard, 1969]. Electronic systems are physically smaller than mechanical ones, and more modular in design. Thus, repair usually takes place off-site, in relatively comfortable environments. Little, if any, fabrication of parts is necessary in the repair process. Replacement parts are small, and for the most part cheap and readily available. Modular design makes repair of electronics systems predominantly hierarchical. Faults can be isolated and repaired on several levels: the module, which may consist of many circuit boards; the circuit board, which may contain many discrete components; and, in the case of digital circuits, the integrated circuit level. Thus, depending on the maintenance concept in force for particular equipment and the maintenance level, repair might take the form of isolating and swapping faulty modules, circuit boards, or individual components. Problems arise when the lowest replaceable units called for by the maintenance concept are unavailable, requiring the technician to attempt repairs without proper documentation.

The technical documentation for supporting the maintenance and repair of electronic systems is, of necessity, the most complex. Since electronic circuit operation cannot be seen directly, the documentation is largely symbolic, consisting of two dimensional circuit schematics and functional block diagrams, which are the preferred froms of documentation [Hughes, 1978]. In addition, traditional textual theories of operation and troubleshooting guides are used. Finally, specification lists, graphs, sample waveform illustrations, proceduralized troubleshooting, alignment, and test procedures, and parts lists are employed. Compared to the documentation of mechanical systems, electronics documentation is far superior in terms of availability and information content. This is because these systems tend to be newer, more sophisticated and complex, and hence require more training and sophistication to repair than mechanical ones. However, the quality of organization and detail of documentation depends on the individual equipment involved.

A special problem of electronics documentation is that of timeliness and accuracy. Due to the continual development and change that many systems undergo, new generations of documentation may trail the release of equipment. Thus, applicable documentation may not be available or up-to-date. A related problem results from the existence of multiple configurations of similar hardware, making the task of finding accurate documentation on a specific configuration more complicated. The symbolic nature of electronics documentation, the relative complexity of these systems, and the sophistication needed to repair them, make the electronics area the most amenable to the introduction of new technical documentation media.

A.1.2.3 Electrical and Ordnance

Finally, there are areas which have characteristics of both electronics and mechanics.

In electrical repair (of motors, for example) emphasis is placed on the localization and isolation activities, in which the use of test equipment comes into play. However, the physical disassembly, interchange, onboard parts manufacture, and reassembly phases are still a large part of the work, because of the electro-mechanical nature of these systems. The documentation for electrical repairs combines the 3-D drawings and 2-D blueprints of the mechanical world, with 2-D symbolic schematic diagrams more typical of electronic systems. In addition to disassembly instructions, troubleshooting and test procedures, electrical specifications and parts lists and breakdowns are also found. As with electronic systems, circuit schematics and block diagrams are the preferred forms of documentation [Hughes, 1978].

Ordnance is similar in that it deals with small mechanical and electromechanical equipment.

A.1.3 WORKFLOW MANAGEMENT

Workflow management encompasses the overall management of the corrective maintenance and repair process from the reporting of a problem, the estimation of resources needed for its repair, the scheduling of maintenance personnel, and overseeing of the work through quality assurance and quality control programs. Responsibility for administering preventive maintenance programs also falls in this area.

Equipment problems are generally detected by personnel at the organizational maintenance level who operate the equipment or perform simple preventive maintenance (PM) procedures. Depending on the nature of the problem and the rating of the sailor, he may be able to take care of it on the spot. Otherwise, he fills out an OPNAV 4790/2K Ship's Maintenance Action Form, known colloquially as a "2-kilo" form. It has fields for identifying the ship and particular equipment (location, name, serial number(s)), a narrative description of the problem, the date and time the problem was discovered, and the name(s) of the reporting personnel. The information on this one document is used in administering all subsequent phases of the repair job. It also serves as input to the 3-M reporting system described in Appendix A.1.5. Aviation repair personnel use a different Maintenance Action Form which serves the same purposes.

The information on the "2-kilo" is added to the Current Ship's Maintenance Project (CSMP) file, which lists all outstanding organizational, intermediate, and depot level maintenance work. The other major sources of CSMP information are the scheduled maintenance activities (PM and alterations). The CSMP is intended to be a management tool which reflects the material condition of the ship.

Scheduling of both corrective and preventive maintenance on most ships is done by the Work Center Supervisors, who act as "foremen" overseeing these activities. Scheduling on tenders is done by a Planning and Estimating office. The factors that go into job scheduling include: the list of outstanding work, personnel availability and skills, parts and tool availability, and equipment priorities. A Master Job Catalog lists approximate personnel and material requirements for most "standard" jobs; others must be estimated. Shipboard maintenance scheduling is stictly a manual process at present, and relies heavily on the skill and experience of the individuals doing it. Automation is used only to record and list scheduling information, and to prepare Automated Work Request forms (work orders). The Fleet Non-tactical ADP Requirements Definition Working Group has recommended an interactive computer system which integrates the scheduling, CSMP, and parts and material management functions [Hobler, 1976].

Some maintenance jobs cannot be performed due to the lack of parts, tools, or qualified personnel. These jobs are deferred until materials are obtained or repair facilities (possibly on a tender) become available. Jobs which are not deferred are normally executed as scheduled.

Depending on the ship and the nature of the work, some quality assurance (QA) procedures may be performed during or after the maintenance task is completed. These vary from simple visual inspection to extensive non-destructive testing (e.g., ultrasound fracture tests). Quality Assurance is a major activity on the tender we visited. For many repairs, the QA department assembles (manually) a "control work package" with a copy of the original "2-kilo" form, a parts list, step-by-step maintenance instructions, a bench report, and a final test report. This approach helps insure that a good job is done, but it appears that most ships do not have the resources to generate this kind of comprehensive document on a regular basis. This capability might be possible, however, with an automated technical documentation delivery system.

A.1.4 PARTS AND MATERIAL MANAGEMENT

Parts and material management deals with the supply, distribution, and inventory procedures for materials and equipment necessary for maintenance and repair. The availability of parts often determines whether a maintenance action can be performed or if it must be deferred (possibly to a secondary intermediate maintenance facility, such as a tender). Therefore, parts and material management has a direct impact on fleet readiness.

Ships have limited space for storing spares and tools, and limited facilities for repair. When a ship is commissioned or it comes in for refitting, the Ship Parts Control Center, with help from the ship's Supply Office, decides what goes on each ship.

An Allowance Parts List (APL) specifies what spares the ship may carry. The criteria for determining entries on the APL include size and weight, cost, military essentiality (some items are deemed absolutely necesary to the ship's mission), repair capability (versus replacement), and known and estimated failure rates. Even within these restrictions, the aircraft carrier we visited during the research for this report stocked over 165,000 items, with an aggregate worth of about 100 million dollars.

Most of the parts on a ship are stored in a central supply office, where access to the inventory can be controlled. Pre-expended Parts Bins (PEBs), located near work stations, provide ready access to small, commonly used items. If technicians cannot find the parts they need in the PEBs, they must go to the supply office with a manufacturer's serial number or some other means of uniquely identifying the part. Since ships' inventories are indexed by APL or national stock number, some cross referencing must be done before parts can be located. Increasingly, microfiche is being used for this purpose, since the medium is well suited to handle the high volume of information and frequent update/replication rate of parts lists.

Reconciliation of the various parts lists with one another and the physical inventory, and general inventory control are major shipboard management problems. The process of cross referencing part numbers also consumes the technicians' time. These problems could be alleviated, however, by applying proven administrative data processing techniques [Hobler, 1976].

A more serious and difficult problem is to increase parts availability, by carrying an inventory better matched to real needs. We were told that, on the carrier, about 80% of the requests for non-aircraft parts could be fulfilled from stock — the other 20% had to be deferred, or an alternate means of repair found. The greatest unknown in formulating an APL (and thus the inventory) is the failure-rate data, which depends to a large extent on known failure patterns. Presently, the source data exists for obtaining failure statistics (see Appendix A.1.5), but a facility to actually carry out the analysis is not in place.

A.1.5 FEEDBACK AND DATA COLLECTION[5]

The primary means of gathering data on maintenance and repair activities is the Maintenance Data System, part of the

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[5]The source for this material was a presentation by Paul Ruth of the Fleet Maintenance Support Office, Mechanicsburg, PA, as part of a seminar on Shipbuilding and Shipboard Maintenance and Repair given at the Information Systems Division of the Office of Naval Research, Arlington, VA, on April 27-28, 1978.

Navy's Maintenance Material Management (3-M) program. The objective of the 3-M program (started in the mid-sixties) was to simplify and standardize procedures for shipboard maintenance and repair, and to provide a means for data collection. Maintenance information is collected at the source, once, using the "2-kilo" form described in Appendix A.1.3. Normally, only corrective maintenance data is gathered, but items on a selected equipment list (including safety-related gear) have all related maintenance activities reported. Contractor maintained equipment, missiles, and nuclear ships and submarines are not included in the program.

The "2-kilo" forms are transcribed to magnetic tape, on either the originating ship or a tender, and sent to the Maintenance Support Office in Mechanicsburg, PA for processing. About 3 million transactions per month are handled by the system. ADP Programs running on a large computer produce printed reports which are intended to help management gain insight into system and operational costs, reliability, and manpower requirements. It was also hoped from the program's inception that it would help identify potential catastrophic failure patterns.

These goals have been met to some extent, but extracting such information is difficult and time consuming: the database is extremely large (data has been collected for nearly 15 years), and a new program must be written for each query. At present, no real-time "information retrieval" capability exists for analyzing the database. In addition, the data is often months old before it is input to the system, since the tapes are sent to the Maintenance Support Office only when ships go into port for intermediate maintenance. Delays in processing and reporting mean that the identification of "urgent" problems can take half a year or more.

A more responsive feedback system (possibly tied to an automated shipboard technical documentation delivery system) would clearly benefit maintenance and repair activities. Better tools for analyzing the database could provide quicker and more reliable identification of equipment failure patterns. This is important for safety reasons alone. Failure rate measurement and projection also facilitates the generation of Allowance Parts Lists that more accurately predict actual stockroom needs, thereby reducing deferrals due to unavailable spares.

However, any analysis is only as good as the source data on which it is based. Two problems exist with the present method of collecting data:

- Sailors are sometimes reluctant to fill out the "2-kilo" form (some needed repair work is never reported). This is not necessarily something that technology can solve.

- Much of the really useful data is in the narrative section of the "2-kilo", which at this time is not machine processed. Computer understanding of "natural language" narratives is still a major research problem, and it is not clear when such techniques will be feasible.

A.2 Technical Documentation Technology

A.2.1 PRESENT DOCUMENTATION FORMATS

A.2.1.1 Paper

Formal military technical documentation is currently presented in several different formats, the use of which varies between the services and among the system commands within the Navy:

- Traditional text oriented manuals,
- Functionally Oriented Maintenance Manuals (FOMM),
- Job Performance Aids (JPA),
- Work Packages (WP), and
- Blueprints, reference cards, and other documents.

While traditional text oriented manuals are the most prevalent form, increasing use is made of FOMM (by NAVELEX and NAVSEA), WP (by NAVAIR), and JPA (by the Army and the Air Force) [Hughes, 1977]. These formats are described below.

• Traditional Text Oriented Manuals

Traditional technical manuals are largely text oriented, with illustrations supporting narrative descriptions found in the text. The types of illustrations include line drawings, photographs, and schematics, and account for 15-20% of manual image area [Chenzoff, 1973]. The text includes equipment descriptions and theories of operation, and can be compared, in style and format, to liberally illustrated high school textbooks.

Since they include descriptive theory, rather than trying to cover every situation that may arise in the operation and maintenance of the equipment, they rely to a great degree on the reader's intelligence. However, these manuals also contain a large amount (30-40% of total image area) of procedural information [Chenzoff, 1973]. These procedures are related to tasks, such as assembly, disassembly, or repair, which can be accomplished by following a fixed sequence of steps, as opposed to troubleshooting procedures which require decision making. Typical manual size is between 100 and 300 pages.

• Functionally Oriented Maintenance Manuals (FOMM)

The FOMM is a two volume manual oriented exclusively toward maintenance and repair, in contrast to traditional manuals which provide information to suit all major users. One volume contains sections on general equipment characteristics, operating instructions, theory of operation, scheduled maintenance instructions, installation instructions, test procedures, and a parts list. The other contains troubleshooting and repair information: configuration breakdown, turn-on checkout chart, functional diagram, schematics, repair and alignment procedures, and repair parts data. The major problems FOMM presents are large size (both in page size and number) and inapplicability to mechanical systems, since they are oriented toward functionally hierarchical electronic systems.

The FOMM uses color coding to illustrate hierarchical functional and hardware levels, down to the smallest functional entity in the equipment. In addition, FOMMs make use of maintenance dependency charts keyed to the color coded units (usually sections of circuit schematics), for fault isolation by a series of checkpoints. These are matrices which illustrate the conditions necessary for the operation of some function by showing the relationship between physical components and functional events. The charts depict the dependency of one event (e.g., the presence of a signal) upon another (the availability of a voltage), in a tabular format which allows the technician to follow a logical sequence of steps to determine the cause of a problem. Thus, the technician does not need to rely on extrapolation from theory. However, the cost of developing a complete set of charts for a system is quite high and technicians often find them confusing and difficult to use.

• Job Performance Aids (JPA)

There are two kinds of JPAs: Fully Proceduralized Troubleshooting Aids (FPTAs) and Job Guides.

Fully Proceduralized Troubleshooting Aids are a series of step-by-step action trees, showing the steps necessary to isolate hardware faults. These action trees are tied together by Checkout Procedures, which link the action trees by a flowchart notation for identifying test decision points, fault isolation procedures, and repair and replacement procedures.

Job Guides are narrative procedures which cover instructions for performing organizational maintenance other than troubleshooting.

Supplementary manuals are used to provide data, such as specifications and parts lists, that does not fit into either format.

These manuals differ from traditional technical manuals in that more emphasis is placed on structured task analysis in their preparation, to achieve procedural data that relies less on the technician's intelligence. In addition, illustrations are emphasized over text, with 30-40% of the image area of JPAs devoted to line drawings and schematics (no photographs). The manuals are formatted to reduce page flipping during steps of a procedure, with illustrations on each page keyed to procedural text on the facing page. This results in a great deal of redundancy, since the same illustration may be used many times. Thus, while the page size of a JPA is smaller than that of the traditional TM (5"x7.25" vs. 8.5"x11"), there tend to be more pages in a JPA (200 pages average, with a maximum of 300 by military specification).

JPAs are traditionally oriented toward mechanical systems, since the amount of work necessary to produce a good manual for complex electronic systems makes them prohibitively expensive [Hughes, 1977]. Nothing in the JPA format, however, would preclude their use with electronic systems.

• Work Packages (WP)

The Work Package concept emphasizes a series of short (12-15 pages are considered optimal, but no more than 30 pages by military specification) stand-alone work units which are organized by functional tasks. Several work units are combined to form a WP manual on a particular system. These manuals emphasize the use of illustrations over text wherever possible, as well as proceduralized instructions and checklists. They are designed for microform reduction, and can be reproduced in pocket size. The major difference between WPs and traditional technical manuals is in the organization of data by functional task.

The WP is said to have advantages over other forms of technical documentation because it presents information in small, easily understood chunks. Its major disadvantage is that its task-oriented organization can make it hard to find specific information.

• Blueprints, Reference Cards, and Other Documents

Besides the technical manuals, shipboard documentation in operational use includes blueprints, reference cards, and special documents such as parts numbering lists. As noted in Appendix A.1.2, blueprints are a primary source of information to those doing maintenance and repair on mechanical systems. Ships maintain a blueprint file as part of their technical libraries. However, our shipboard observations indicated that although technicians find the blueprints useful, the library file is often incomplete, especially in older ships. Either the documents never existed in the library from the beginning, or they were lost over time, with no replacements available.

Maintenance Requirement Cards (MRCs) are laminated reference cards with safety and preventive maintenance instructions for an individual piece of equipment. They are used with great success in the areas of electronics and ordnance. MRCs are organized to provide a handy source of information for the most common maintenance tasks, and are also intended to lessen the use of technical manuals.

A.2.1.2 Microform

Microform has been applied with some success in the Maintenance Information Automated Retrieval System (MIARS) developed by NAVAIR and the Technical Manual Microfiche Program developed by NAVSEA. Both programs retrofit existing paper documentation to microform. Standard formats include 16mm roll microfilm, 35mm aperture cards, and 105 x 148mm fiche.

MIARS employs 16mm microfilm cartridges with an automated search console and a reader/printer for obtaining hard copy. The Technical Manual Microfiche Program uses a simple viewer/printer with 98 frame fiche. Preliminary reports of both projects indicated user acceptance. However, later surveys [Hughes, 1978] show considerable dissatisfaction with microform as a replacement for paper because of the disadvantages cited in Section 2.2. Nevertheless, most technicians thought microform a good solution for parts and supply system ordering.

A.2.1.3 Traditional Audiovisual Media

Traditional audiovisual media (film, filmstrip, videotape) are not in widespread use for direct maintenance and repair support. In addition to problems of ruggedness and portability, their serial, lockstep presentation is not suitable for on-the-job task direction. However, these media do find use in training.

A.2.2 USE OF COMPUTER AUTOMATION

There has been no operational use of computers as a medium for automated technical documentation storage and presentation employing any of the techniques described in Section 3.1. The role of computers in military technical documentation programs has been limited to text processing for technical manual production [Touchton, 1975; SRI, 1976], and the maintenance of engineering databases for vendor product development and associated documentation production [IPAD, 1977; Southall, 1979]. The major uses of non-tactical military computing have been in supply inventory management, maintenance and repair work scheduling, and maintenance data collection and reporting (e.g., the 3-M program, discussed in Appendix A.1.5). These applications employ standard ADP techniques for data collection, database management, and report generation. Such uses for computers are being expanded, especially in the area of maintenance data collection and analysis to support better scheduling of preventive maintenance procedures [AMS, 1978; Cook, 1978].

A recent Navy task force recommendation for the expansion of shipboard non-tactical computer usage (SNAP-2) [Hobler, 1976] includes a more fully integrated program of ADP in the parts and material management and workflow management areas than that in force today. It also specifies a program for placing an index of available technical documentation (both manuals and drawings) online. However, the index would be interfaced to microform reader/printers instead of employing CRTs or graphics terminals for direct documentation presentation.

A.2.3 SIZING ESTIMATE

Recent estimates of the number of Navy technical manuals state that there are between 120,000 and 135,000 different technical manuals in use. These comprise approximately 25,000,000 pages, which contain 60-70% text by area [Hughes, 1977]. The average number of pages per manual is between 200 and 300, depending on the manual's format. A breakdown of these figures by system command is given in Table 2.

System Command	NAVSEA	NAVELEX	NAVAIR
Percentage distribution			
(by number of manuals)	68	14	18
(by number of pages)	81	10	9
New manuals per year	10,000	500	1,100
(thousands of pages)	2,850	77.5	110
Updates per year			
(thousands of pages)	240-400	50-75	40

Table 2: Naval Technical Documentation Distribution[6]

These figures represent a trend that has been stable for the past few years. Barring any changes in overall procurement policy, it is estimated that the volume of technical documentation production and updates should continue to expand for the next five to ten years.

Thus, any systems proposed for automating the storage and/or production of this documentation in a ten to twenty year time frame must be capable of storing upwards of 30 million pages of information, with an annual growth rate of at least 4 million pages. Of this information, currently one-third is graphics, and this figure can be expected to grow, given the effects of such existing technical documentation improvement programs as NTIPP which calls for increased emphasis on pictorial information over text in new technical manuals.

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[6] Figures from [Hughes, 1977]

A.2.4 THE PIPELINE FOR MAINTENANCE AND REPAIR TECHNICAL DOCUMENTATION

Technical documentation for maintenance and repair has a life cycle which parallels those of the systems it supports. This life cycle can be decomposed into the following stages:

- planning and design,
- authoring,
- data capture,
- replication,
- distribution,
- feedback, and
- updating.

For Navy technical documentation, implementation of each of the above steps varies with the procuring System Command (SYSCOM), contractor, equipment being documented, and types of documentation being produced. There is no single, representative "pipeline" for the development of Navy technical documentation; in fact, the lack of uniformity has been cited as as major source of problems with the present system [SRI, 1977]. However, the life cycle stages listed above provide a general framework for discussing the development of Navy maintenance and repair technical documentation, particularly for the identification of the problems and bottlenecks that exist in current systems.

• Planning and Design

The life cycle of a technical document starts with its planning and design phase, which typically begins during bidding on equipment and ends shortly after the contract has been awarded. A set of planning documents, known as bookplans, are developed which describe the contents of the proposed technical documentation in outline form. They become both a baseline for monitoring later phases of technical documentation development and a framework for the authoring process. Inputs to the planning phase include system specifications, available engineering and manufacturing information, contract requirements, and the system maintenance plan.

This phase has great impact on the final technical documentation, and yet it suffers from some serious problems:

- The available technical information, particularly maintenance requirements, is not always stable or reliable. For example, the preliminary equipment design, system maintenance plan, and technical documentation plan are often developed in parallel during the design phase which is characterized by constant change, because all of this information is required before a contract can be awarded.

- Military technical manual specifications do not always accomodate the particular equipment's maintenance needs, as in the case when new or innovative maintenance concepts are utilized. This can have an adverse effect on the effectiveness of the technical documentation.

- Severe cost and time constraints often exist because much of the work is done at the contractor's expense, before the contract is awarded.

In short, the problems at this stage appear to be largely procedural, managerial, and economic in nature. One proposed improvement is to simply delay the delivery dates for technical documentation plans to allow a design based on (nearly) correct and stable information [Hughes, 1977].

• Authoring

Once the initial design of the equipment is complete, the authoring (or "content generation") process may begin. Technical writers work with the bookplans developed earlier, and with information supplied by design engineers and derived from engineering, manufacturing, and maintenance documentation to generate draft technical manuals. The drafts are iteratively reviewed and refined, and artwork is added to produce complete manuscripts. Factors influencing the content of a manual include formal specifications and writers' guides, the author's writing skills and familiarity with the subject area, the complexity of the equipment, and the available data on it (which is subject to change). The inevitable cost, size, and time constraints also exist.

As in the planning and design stage of technical documentation development, most of the problems in this stage are non-technological in nature:

- Technical writers have low priority, and therefore difficulty, in gaining access to hardware which is being used for development.

- The primary source of data on the equipment is the database used for engineering development. This information is not oriented for the development of maintenance technical documentation, so the writer must manually extract and assemble the information he needs, which is a difficult and time-consuming task. Greater integration of technical documentation development with engineering development might help to alleviate this problem (see Section 3.2.1).

- The writing phase and the revision/review process lack direct input from the user community. In fact, little consideration is apparently given to the actual data needs of the user, or the relationship between training and the material contained in the technical manual [Hughes, 1977]. The Army's SPA program [ARTADS, 1977] is is an example of an attempt to address this last point.

Advancing technology is having some direct impact on the technical writer, and will have a much greater impact in the future. Text processing systems have been proven to speed up the revision and review cycle for hardcopy manuscripts. More significantly, new computer-based systems for technical documentation presentation will require new authoring tools, and authors skilled in using them (see Section 3.1.4.1).

• Data Capture

Information generated during the authoring process must be captured for the production of working drafts and final copies ready for replication. Initial input and editing of text falls under the area of "text processing". "Graphics processing" is the analog for artwork and other non-textual material. Techniques for doing both vary widely at present:

- In totally manual systems, new drafts are completely retyped manually, and all artwork and layout is done by hand. This is the traditional method of data capture and generation.

- Text processing systems (which may be anything from a "smart" typewriter to a time-shared computer) allow text to be entered once into a machine, edited online, and output fully formatted on a printer or phototypesetter. Page layout is automated, while graphics are handled manually. These methods are becoming more widespread in the production of Navy maintenance and repair technical documentation as increasing volumes of material, coupled with escalating labor costs and lowering equipment prices, make these systems cost-effective.

- Some systems, such as that employed in the NAVAIR Technical Review and Update of Manuals and Publications (TRUMP) program, accept both keyboard input and existing typeset material, which is read by optical character recognition (OCR) devices. This appears to be the only practical technique for entering old technical manuals into new production systems.

- Computer-aided drafting equipment, such as that manufactured by Tektronix and Applicon, can be used for entering and manipulating line art for publication. These systems are particularly effective for engineering drawings, since they often will accept machine-readable data generated by computer-aided design and manufacturing (CAD/CAM) equipment, thereby eliminating manual copying.

Although automation has helped in the domain of data capture, some significant problems remain:

- Interactive graphics systems have not yet gained wide acceptance in publishing, despite their effectiveness in dealing with 2-dimensional line art, symbolic/schematic diagrams, and other design and manufacturing artwork. One reason may be the unfortunately prevalent perception of technical documentation as an ancillary activity. While a CAD/CAM graphics system directly assists the development of a product, a system with the same kind of sophistication cannot be as easily cost-justified for the production of the associated documentation.

- Standards do not yet exist in the automated text processing and graphics industries. This often makes interfacing or transporting data between unlike systems difficult. It impedes the integration of automation into the technical documentation development process.

- The "retrofit" problem of applying new delivery systems to old technical documentation will have to be addressed, as such documentation will be in use (and thus subject to revision) well into the future. The OCR method described above is only a partial solution to this problem, because it captures the text and graphics without the structuring information needed for interactive manipulation (see Section 3.1.4.3).

The volumes of technical documentation handled by the Navy are staggering (see Appendix A.2.3): a 25,000,000 page inventory with a ten percent annual growth rate. This makes the move to automation imperative, especially in the labor-intensive area of data capture. Even capturing the raw text and graphics without imposing structuring is still preferable to not capturing this information at all. Numerous studies, such as [SRI, 1976] have shown that the needed technology already exists.

• Replication

Replication of a technical manual is dependent on the medium used for distribution (predominantly paper), the volume of material, and the source of the master copy. Nearly all Navy technical documentation printing is done by the Naval Publications and Printing Services Office (NPPSO) or its subcontractors, using conventional paper and microform publishing technology. Large runs of paper manuals are done on standard printing presses, while small volume or fast turnaround requests are produced by Xerographic or similar processes. Microform is often used solely as a medium for distribution and storage: when a document is needed by a user, a paper copy is made locally.

Replication technology and its use within the Navy is fairly well established. This is not suprising, considering the maturity of the printing and micropublishing industries. However, new media, such as optical disks or entirely electronic methods of distribution (e.g., satellite transmission) may alter the picture considerably. Optical disks offer several orders of magnitude increase over paper in storage density and require a completely different replication technology. Electronic distribution goes even further, as it essentially eliminates the need for replication at a central site.

• Distribution

Distribution encompasses the storage, retrieval, and physical delivery of technical documentation, and the managerial activities of configuration and inventory control. Note that some of the managerial activities start early in the life cycle of a document. There are three classes of distribution which must be considered:

- Initial distribution occurs when technical documentation is first deployed. At this time configuration control is initiated, volume requirements are determined, and the documents are actually delivered.
- Resupply is done in response to user requests. Inventory control is important here.
- Archiving is the management of the "masters" used for replication and resupply.

Each Navy SYSCOM has its own procedures and agency to control the distribution function, but all use the Naval Publications and Forms Center (NPFC) and the normal supply channels for the physical distribution of technical documentation.

The Hughes NTIPP study [Hughes, 1977] indicated that the Navy technical documentation distribution system works, but more slowly than the users would like. Delays are due largely to the vast amount of paper which must be printed, managed, and physically transported. If technical documentation could be transmitted quickly from a central, efficiently encoded digital archive to the user site for local replication or display, the time and energy expended in producing and moving paper, and the need for central printing and bulk storage facilities, would be eliminated.

• Feedback

User feedback on Naval technical documentation comes from three sources: maintenance reporting systems, tear-out comment sheets from manuals, and surveys. The reporting systems, such as 3-M (see Appendix A.1.5), or NAVAIR Unsatisfactory Reports, are oriented towards equipment reporting and have no special provisions for technical documentation related problems. Comment sheets are included with technical manuals, but their use is entirely voluntary. Properly conducted surveys can gather comprehensive information on technical documentation usage patterns and deficiencies, but they are expensive.

Most of the feedback mechanisms in the Navy include sending a response to the originator of the report. This lets users know that the system is responding to them and encourages them to use it. Most reports are classified as "routine", and are responded to within 45 days. "Urgent" reports involving safety-related problems are handled within 15 days, while serious "emergency" matters are taken care of within a day. On the other hand, actual changes to the technical manuals due to user feedback take six months to a year, or more, depending on the urgency of change and the length of the update cycle.

• Updating

Updates to Navy technical documentation, whether they are revision pages or completely rewritten manuals, go through the same process of authoring, capture, replication, and distribution used to produce the original documents. Updates may be made to reflect hardware changes to the documented equipment, or to correct deficiencies reported by users through the feedback mechanisms described above. Three major problems exist with the present update system:

- It is too slow. Changes to technical publications can take a year or more to propagate through the system. This is an especially serious problem for safety related information.

- Updates are often technically or stylistically inferior to the original material, since they are usually produced by a different group of technical writers who are not as familiar with the equipment as the original authors.

- Configuration control is necessary to maintain accurate records on the status of technical documents and the technical documentation inventory of users (so that updates may be propogated). It does not appear that this need is being met [Hughes, 1977].

• Summary

As with other documentation production pipelines that have been studied [Irvine, 1979], classical problems exist, many of which could be ameliorated by judiciously applied automation and a change of medium from hard copy to digital:

- lack of up-to-date, complete, and consistent source material,

- inadequate facilities for entering and editing text and illustrations,

- hardcopy media which are too expensive and too slow to replicate, distribute, update and manage, and

- lack of coordination between producers and consumers of technical data for design, training, and maintenance and repair.

Experience in introducing new technology in large establishments with a great deal of history, infrastructure, and consequent inertia has shown that enormous effort is required to make new technology gain acceptance and pay off. Therefore, we expect that the introduction of new media such as those postulated in Section 3 will be accompanied by major, even painful changes in systems and procedures for using and managing them.

APPENDIX B : REFERENCES

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