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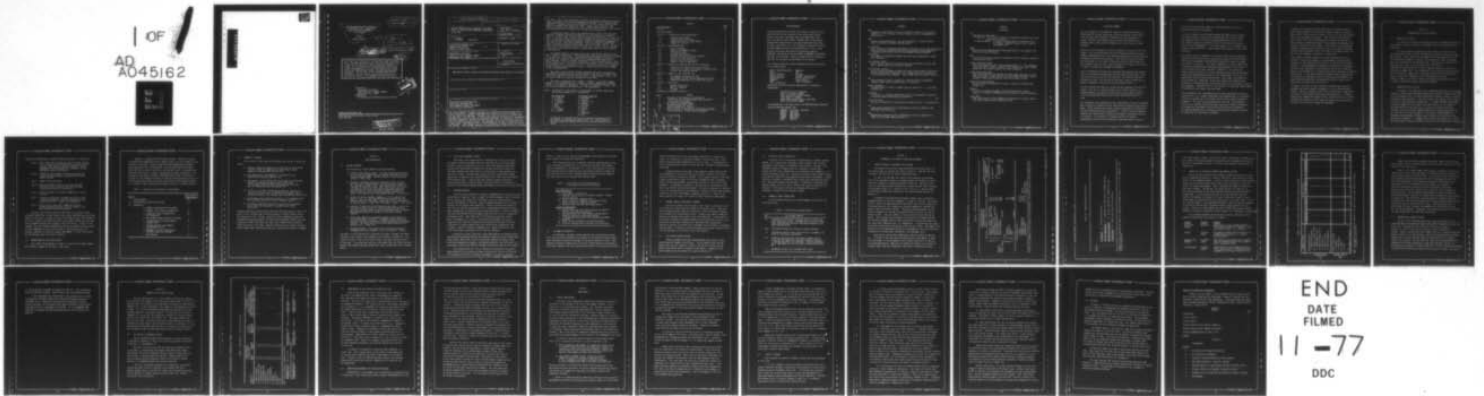
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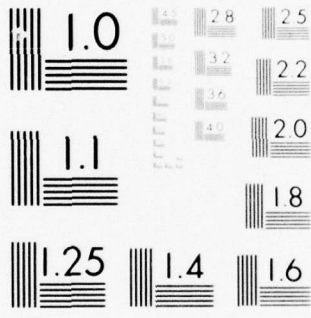
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6 THE NAVY MANUFACTURING TECHNOLOGY
ELECTRONICS STUDY, - A PLAN FOR
COST EFFECTIVE ELECTRONICS
IN THE NAVY,

Volume I.
STUDY SYNOPSIS.

10 T. M. / Krasel
J. T. / Mc Gahan

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This report was prepared for internal Navy planning purposes only. The data contained herein, while accurate at the time of publication (June 1977), may be subject to frequent revision. It is expected that the program described will be further developed prior to Fiscal Year 1980 due to further review, new technological inputs, and changing procurement priorities. The U.S. Navy is not presently committed or obligated in any way to carry out or follow all or any of the specific projects or recommendations described herein.

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Washington, D.C. 20360
Prepared by:
SAI Manufacturing Technology Project Office

SCIENCE APPLICATIONS, INC.
8400 Westpark Drive, McLean, Virginia 22101
(703) 821-4300

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This study examined investment opportunities in Manufacturing Technology (MT) related to electronic systems procurement and presents an initial candidate plan for the FY80 to 84 timeframe. The major cost areas for electronic products were determined by a top down study of the detailed breakout of electronics subcomponent and labor categories. Results indicate that about half of electronics costs are found in seven key material areas. The remainder of the cost is apportioned into 4 labor areas. The breakout into 11 final categories is based on data for nearly 100 systems. These systems represent a broad spectrum of Navy electronics procure-		

20. ment. The 11 cost categories are cables and cabinets, sensors and special tubes, integrated circuits, small hardware and printed circuit boards (without components attached), discrete semiconductors, hybrid circuits, passive components, assembly labor, fabrication labor, support labor, and test labor. These data are used to estimate net direct savings from MT projects, where applicable opportunities for indirect cost savings are indicated also.

To determine project impact and program balance specific cost data were obtained on weapon systems procurement by visiting 58 Navy and industrial offices. Of the fifteen firms visited 90 percent provided data in at least one area. During the review of these data, an additional way was found to look at costs by reviewing the generic processes involved in manufacture. Breakout of four process cost areas was determined: These are volume of production, capital equipment, manufacturing methods, and institutional effects. Assessing these areas of manufacturing (that of product and of process costs) provided a new view of the candidate projects, and has been used as a tool to achieve program balance.

An economic analysis of present value costs and savings of projects was made. Technical evaluation of the projects was made and included in the economic analysis as a risk factor. Project percentage estimates of savings, in particular cost elements, are multiplied by the appropriate population of those elements in the procurement to determine final results and project rank. Project savings over a 4-year base period were allowed, with an average savings to investment ratio in the range 15 to 30. The analysis technique is computer based, allowing quick up-date for review of further projects, or for changes in the procurement data.

The study results include findings concerning the plan, its near-term improvement, and suggestions as to the incentives required to stimulate industrial participation in the FY82-84 time period. A key finding is that a significantly larger MT program is economically justifiable.

The study is organized into 3 volumes. Volume I is the Study Synopsis. Volume II is a candidate MT plan. Volume III contains appendices providing details of the specific study tasks. The table of contents of Volume II and III are also included at the end of Vol. I for convenience.

Note: Contributors to this report included members of the SAI Study Team and MT Review Committee as listed below:

SAI Study Team

- T. M. Knasel
- S. Gustaves
- J. T. McGahan
- J. W. Miller
- J. Moon
- E. Muller
- C. H. Putnam
- A. D. Stament

SAI Review Committee

- J. Beitchman
- W. Bradley
- J. Connolly, Jr.
- D. Heebner
- F. Horrigan
- W. Layson
- P. Poulsen
- K. Pope
- J. Schneider
- W. Sooy

In addition, F. Varcolik assisted with computer programming during the project and designed the report cover. Mrs. Betty Lancaster provided secretarial support during the project and typed the final report.

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NAVMIRO	O. Wilsker, Chairman
NAVELEX	CODE 5045
NAVAIR	CODE 52022
NAVSEA	CODE 06H1D
NAVMAT	CODE 0343
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GLOSSARY

CAD

Computer assisted design; the use of computers especially with graphic terminals to aid in design, produce drawings, assist in programming of machine tools

CAM

Computer aided manufacture; the use of computers to control machine tools, especially in groups (see DNC below)

Cost Factors

Costs related to categories identified as universal for all Navy electronics; final cost factors are derived from eleven hardware related categories (7 material and 4 labor) and four non-hardware related categories.

Cost Driver

The elements of weapon procurement that are costly themselves or impact cost indirectly.

Cost Savings, Direct

Dollar savings resulting from the direct cost reduction of a cost category. Implies little or no product redesign.

Cost Savings, Indirect

Dollar savings to weapons systems resulting from the reduced stress, load or other requirements brought about by a change (positive or negative) in an electronics cost category. This savings requires product redesign.

DNC

Direct Numerical Control, control of a machine tool by programmable computer rather than by punched tape as in normal NC.

Group Technology

The manufacture of items in common groups of operation, i.e., drilling, cutting, etc.

Incentive

A financial, or business opportunity used as an inducement to industry to achieve better manufacturing productivity

Life Cycle Costs

The cost of ownership of an electronics system (see Vol. III, Appendix E)

LSI

Large Scale Integration (of a semiconductor circuit); generally over 100 logic gates per device

MSI

Medium Scale Integration (of a semiconductor circuit); generally at least 12 to 100 logic gates per device

MANUFACTURING TECHNOLOGY STUDY

GLOSSARY

- continued -

MT

Manufacturing Technology:

In general: The art of utilization of innovative processes to produce goods more efficiently

In Navy documents: A program to expend funds in industrial firms to achieve increased productivity and lowered procurement costs

NEMTA

Navy Electronics Manufacturing Technology Analysis, the computer code utilized to rank MT projects

PCB

Printed circuit board; connects integrated circuits and other components into functional units

Product-Associated Costs

Costs associated with what is being manufactured, i.e., the components of an electronics system - broken out into material and labor, further broken out into various material and labor categories

Process-Associated Costs

Costs associated with how something is made rather than what is being made (see above) - broken out into factors related to volume, capital equipment, manufacturing methods, and institutional factors

Reduction of Labor Content

The substitution of machinery for labor in order to increase labor productivity

Robotics

The use of automated equipment to replace human labor content - especially in regard to manipulation and functions requiring dexterity

Touch Labor

Labor associated with the assembly and fabrication of devices; operations which require actual touching of parts

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EXECUTIVE SUMMARY

This investigation of the potential impact of improved Manufacturing Technology (MT) on Navy Electronics shows that savings of the order of 15 to 30 times funds invested in Electronics MT are attainable. It further indicates that a Navy program at twice the planned level of \$20M/year over 5 years would be rewarded by similar returns on funds invested.

Results of the investigation include a candidate five-year plan for the conduct of an Electronics Manufacturing Technology program and a novel, computer implemented process for continued evaluation of the manufacturing technology initiatives and proposals. The resulting evaluation places any new proposal in its proper relationship with all other elements of the program in terms of risk, cost and potential for future cost savings in specific planned Navy equipment procurements.

Some 101 candidate MT projects are evaluated and ordered by the application of the computerized procedure and that ordering constitutes a baseline MT plan (as of mid FY77) for electronics for FY80 and FY81 with extensions to FY84. The listing also provides a concise format for an annually renewable five-year plan for Navy electronics MT.

The plan reported here does not include already scheduled FY78 and FY79 projects, nor does it include savings due to indirect effects, e.g., lowered weight or decreased life cycle costs due to higher reliability. It is anticipated that the plan will evolve considerably prior to FY80.

The information base developed for this investigation include 50 separate Navy electronics program activities (68 percent coverage of Navy procurement). These programs were viewed from Navy Program Office perspectives and from performing industry perspectives. Further selection produced a balanced set representing a 20 percent coverage of electronics activity in the Navy. The uniformity of response and the very general applicability of much of the electronics technology leads to the con-

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viction that the findings apply to a significant portion of the remaining 80 percent of the program.

In order to quantify the MT program savings and identify cost drivers a "top down" analysis of electronics manufacturing costs was performed. This approach allows an across the board evaluation of costs in all Navy weapons systems, and provides a basis for evaluation of project returns after implementation. Eleven key product (i.e., hardware) cost categories were quantified. These include seven material and four labor categories.

The economic analysis conducted as a portion of this effort showed that characterization of electronics systems costs solely by product oriented factors was not adequate. The additional dimension of process oriented cost factors is required. This latter dimension is of great significance in planning a Manufacturing Technology program because it cuts across a large fraction of the total electronic production. Key factors are volume (rate) and continuity; capital equipment posture and capitalization incentives; manufacturing procedures; and institutional factors such as depreciation practice and pricing policies. While some of the above are on the margins as "technology" issues they interact with manufacturing technology in determining the price the Navy pays for its electronic systems and components. Identification of "cost drivers" as those high impact aspects of both process and product costs were made.

The investigation also highlighted the fact that non-hardware electronics systems costs, e.g., software development and documentation, are a growing fraction of systems costs that should receive efforts toward "production economies." The study also spotlighted the fact that "low technology" areas such as cabling, cabinets and power supplies are major contributors to systems costs and appear to be particularly attractive candidates for improved manufacturing technology because they are necessary elements of practically all electronics equipments.

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A summary of the program indicates that the 101 candidate projects have savings potential for 34 specific weapons systems including the Aegis system, fighter aircraft avionics, such as the F14 radar systems, and missile and weapon electronics. These savings are distributed fairly evenly over the 11 identified key cost areas of material and labor; however, considerable impact is anticipated from upgrading the quantity and quality of the projects. Descriptions of the candidate projects reviewed typically involve the use of an innovative manufacturing or test technique for the first time in an assembly plant, and may be at the component, subsystem, or system level.

In the FY80-81 timeframe projects in improved PCB fabrication and testing, in lower cost cabinets, and in automated system tests were responsive to the identified cost drivers. In the out years FY82-84 projects in the development of manufacturing processes for semiconductor device and integrated circuit materials such as III-V compounds, Sapphire, and dielectrically isolated Silicon were responsive to material cost drivers. In the same timeframe innovative robotic manipulation, increased use of high power lasers for fabrication and assembly, and group technology manufacturing organization appear to have a good opportunity to reduce labor cost drivers.

In summary, the field of Navy electronics provides many attractive opportunities wherein modest investments of funds promise manyfold returns. Room for innovation exists both in the product technologies per se and in the processes associated with manufacture. A vigorous, aggressively promoted MT program in Navy electronics offers a positive and effective incentive to the industrial organizations who provide the Navy its electronics systems and components.

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Section 1

INTRODUCTION TO THE STUDY REPORT

1.1 PURPOSE OF THE STUDY

This study was initiated to determine the best investment opportunities for the Navy to reduce electronics procurement costs through manufacturing technology.

The study guidelines required that cost drivers be identified by a top down approach, that included representative electronic systems from many Navy weapons. Direct savings in procurement costs were emphasized for the near term period (FY80-81). Indirect cost savings and incentive programs were to be outlined for the FY82-84 period. The plan was to represent the best industrial ideas as of mid 1977 but was to be easily updatable to allow the benefit of new or improved industrial projects or altered procurement data. The ultimate goal of the study was to provide the Navy with positive suggestions to implement a manufacturing technology program in electronics, responsive to the identified cost drivers. Further, a means to continue to improve and update that program, and a way to quantify individual project success was requested.

1.2 ORGANIZATION OF THE STUDY

In response to the DoD directives to implement Manufacturing Technology Programs in each service the Navy ordered that a series of studies be performed in key procurement areas, including shipbuilding, weapons, ordnance, aircraft construction and electronics. The latter area is the subject of this report. The Chief of Naval Material (through Capt. L. Dittmar, MAT 042) established a steering committee in July 1976 to set basic policy for the conduct of the electronics MT study and to act as a quality assurance supervisor. The Naval Electronic Systems Command (NAVELEX) was assigned responsibility for direction of the work through Mr. Carl Rigdon, Program Manager for Manufacturing Technology in NAVALEX and Electronics MT Study Director on the Steering Committee. In December 1976, Science Applications, Inc. (SAI) was placed under contract by NAVALEX to perform the following tasks relating to a

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manufacturing technology investment opportunity analysis in electronics:

- Task A. Form a data base of industrial and service MT information in the areas of microelectronics, electro-optical devices, power supplies, passive components, active components, electronic materials, assembly, testing, packaging, sensors and antennas.
- Task B. Prepare for and schedule interviews with Navy and industrial project managers concerning MT for Navy weapons systems.
- Task C. Conduct these interviews.
- Task D. Make an economic analysis of cost data for Navy electronics and of findings from the interviews; identify cost drivers in electronics.
- Task E. Select MT projects from those suggested as a result of Task C.
- Task F. Schedule a selection of potential MT projects over a time period FY80-81. Describe extensions of that program to FY82-84. Predict cost and benefit.
- Task G. Write a final report that summarizes the work accomplished and displays a concise format for the Navy 5-year MT plan in electronics.

The goal then of this electronics MT study is to outline the best investment opportunity for Navy funds in the area of Manufacturing Technology apparent in mid 1977. A budget of \$20 million (20M) per year FY80 through 84 was to be assumed at the outset and used in the study although the study team could recommend funding level changes in the final report. Savings in procurement cost associated with manufacture were to be treated to the exclusion of other components of the Life Cycle Costs. The plan was to be conveniently updatable to allow for program improvement. A draft final report was due 100 days after the start of contract.

1.3 ORGANIZATION OF THIS STUDY REPORT

This report (Study Synopsis, Volume I) is the first of three volumes and includes a summary of all tasks in the study.

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Volume I is organized into five main sections. Section 1 contains the purpose and organization of the report as well as a brief summary of the findings of the study. Section 2 describes the methodology and presents abbreviated results of the interviews. The rationale defining the Navy 5-year MT plan is given in Section 3, and the plan itself is presented and described in Section 4. Finally, conclusions are given in Section 5. The remainder of the report includes a candidate Navy MT plan in electronics (Volume II), and complete write-ups of tasks and associated data (Volume III). The following table (Table 1) relates task results to the appropriate part of the report. Further information on Volume II and III is found on page 30.

Table 1. Location of Task Results in Study Report

<u>Volume</u>	<u>Reports Results from Tasks</u>
I - Study Synopsis	all
II - Candidate Navy Electronics MT plan	E,F
III - Appendices:	
A Summary of Electronics MT Projects	E
B Summary of MT Incentive Suggestions	E
C Industrial Interview Objectives and Procedures	B,C
D Army ECOM Conference Specific Findings	C
E Top-Down Analysis of Navy Weapons Systems Costs	D
F Economic Analysis and Computer Program Description	D
G Equipment List and Study Results Related to Specific Equipment	C
H Bibliography	A

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1.4 SUMMARY OF FINDINGS

As the result of the study the following six principal findings are noted:

- 1) Average savings/investment ratio of about 20 can be achieved based on a plan for expenditure of about 40M in 100 MT projects in FY80 and FY81 (Section 4.1)
- 2) Considerably more than 20M/year is justified for the electronics MT projects (Section 4.2)
- 3) Improvements in the FY80-81 plan can be made by putting more emphasis on reducing assembly and test labor costs and increased funding on lower technology material areas such as cabinets and cabling (Section 4.2)
- 4) The MT plan for FY82 to FY84 should emphasize improved incentives to industry, and on indirect cost savings, such as reduced electronics size, weight, power consumption (Section 4.3)
- 5) Non-hardware costs (totaling as much as 1/3 of hardware costs) need increased attention in both timeframes (Section 3.1)
- 6) MT projects need more innovative structure in time phasing and in industrial teaming for increased effectiveness (Section 5)

The data that were collected during the study and that serve as a basis for these six key findings come from the response of 58 Navy project offices and industrial firms. Fifteen industrial firms responded and good cost breakout data were provided by 10 firms; 58 MT candidate projects were submitted by 8 firms; and either cost data or MT projects were provided by about 90 percent of the firms. Specific sections of this report give more details about these findings and Section 5, Conclusions, provides a summary.

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Section 2

STUDY METHODOLOGY

2.1 GENERAL APPROACH

The following six steps summarize the study approach:

- 1) Identify major weapon systems. This was accomplished primarily by review of Navy budget data and through interviews with Navy project managers (NPM). Identify industrial firms under Navy contract. (Tasks A,B)
- 2) Generate a top-down breakout of electronics costs, starting with the overall weapon systems costs and working through to the component and labor items. Data from previous studies and from Navy and industrial firms (Navy contractors) were used. Cost breakouts for individual major systems were prepared. Quantify and rate (up to eleven) the highest hardware cost factors, and quantify major non-hardware factors. (Tasks A,B,C)
- 3) Obtain and rate by economic judgement a list of process cost factors. This list was compiled from data received from the NPM and industrial interviews. These cost factors were related to how the product is made rather than what is made. (Tasks A,B,C)
- 4) Determine if the cost factors found in step 2 and in step 3 are from two different levels for reviewing manufacturing costs. Develop a planning scheme (a matrix) that shows areas of emphasis. Rate candidate projects on economic and technical grounds. (Task D)
- 5) Select and schedule the candidate projects in the context of the planning matrix of step 4. A computer based analysis was used to study the investment and savings resulting from candidate projects. The matrix was used to give program balance and to minimize risk. (Tasks E,F)
- 6) Document findings. The overall lessons learned and general recommendations were condensed into a final report. (Task G)

The details of the workflow and interaction for steps 1 through 6 and their relation to the original task statements are contained in Volume III. The overlap of tasks in the initial steps reflects the tight time constraints of the study. As systems were selected, data quantified, and initial results emerged, the stepwise approach became more closely equated with the individual tasks.

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2.2 SELECTION OF WEAPONS SYSTEMS

The scope of the study required a comprehensive look at all aspects of weapons systems procurement costs over the spectrum of the Navy defense missions on sea, on land and in the air. Over fifty weapons systems were selected that represented a balance over the Navy missions and that were also major defense cost items likely to be procured in large quantity over the next 10 years. The main data sources for costs included Navy budget submissions to Congress, the Five-Year Defense Plan (FYDP), and the Extended Planning Annex (EPA). These systems data formed a computer-based data source against which to analyze project savings estimates and represent 67 percent of the projected weapon systems procurement over the next 10-year period.

2.3 INTERVIEW PROCESS

Since it was not possible to conduct a comprehensive study covering each system and all industrial firms, a sample of project managers, both in the Navy and in industry, was chosen for interviews so as to be representative of current procurements in the Navy. Over 50 separate program activities both in the Navy and in industry were identified. Further selections were made for interviews at the Navy procurement level of representative electronic equipments representing a coverage factor of about 20 percent. A total of 40 meetings with Navy PM and other procurement activities were held for background information on MT. These then led to 18 interviews concerning specific major procurements at 15 firms. Cost breakout percentages, MT project suggestions and incentive information were checked during these interviews resulting in 8 system breakout data sets, 58 MT project suggestions, and a number of specific incentive recommendations. About 90 percent of the firms interviewed provided help in at least one category.

In addition to these interviews, study team members also attended three manufacturing technology meetings and analyzed industrial project submissions. These efforts dealt with a total of about 400 candidate MT project ideas which were condensed by economic and technical analysis into an MT plan for electronics covering the FY80-81 timeframe including 101 specific MT projects.

The projected plan for FY82 to FY84 was not developed to as great a degree because of long range procurement uncertainties and the difficulties of forecasting electronic technology developments five years in advance.

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However, it was clear to industry and government that the area of incentives held a promise for large cost reductions.

The following points are a consensus from the interview phase of the study representing expectations for a successful electronics MT program. They are presented in a prioritized list - first from the point of view of the Navy which focus on lowering costs and avoiding schedule slippage and then from the point of view of industry which also want to lower material and labor costs so as to increase their market share.

Table 2. Prioritized List of Expectations for a Successful Electronics MT Program

Navy Expectations

- 1) Lower weapon systems cost
- 2) Diminish risk of system procurement schedule slippage and cost overruns
- 3) Reduce electronic component costs
- 4) Improve electronic component performance through better control of production process
- 5) Maintain industrial base and surge capacity

Industry Expectations

- 1) Achieve lower cost electronic products for growing military and commercial markets
 - 2) Improve products for these markets through better production control and increased volume
 - 3) Increased DoD buying power and improved procurement schedule
 - 4) Share capital investment risk with Government
 - 5) Develop a broader base of manufacturing technology
-

2.4 TOP-DOWN COST ANALYSIS

A preliminary literature review revealed that little previous analytical work had been performed on the subject of electronics MT (particularly when contrasted to analysis performed in the heavy industrial areas). Some important references dealing with cost driver identification in electronics were found; however, such costs were usually specific to the particular device

MANUFACTURING TECHNOLOGY STUDY

being investigated and did not have general application. Although electronics is recognized as a pervasive element in all system costs, little quantification had been attempted prior to this study. It became obvious that a methodology was needed to define and rank a program of manufacturing technology.

A detailed analysis was made of two important studies dealing with cost breakdowns; an Air Force study of 62 avionics systems, and an Army study of 22 missile electronics systems. The 8 systems covered in this Navy study provided specific data in the areas of submarine sonar, sonobuoys, digital processing equipment, and both gun and missile fire control radar equipment. Considerable uniformity in the electronics cost breakout categories and percent values was determined. This work culminated in a detailed list of the average percent cost breakout of electronics into eleven hardware categories, and four non-hardware categories (Section 3.1, Table 4a, b). These represent the direct cost factors of Navy electronics procurements.

2.5 ECONOMIC ANALYSIS AND PROJECT RANKING

During the economic analysis work in this study, an alternate set of cost factors was identified that related to the process area. These were based on manufacturing volume and continuity, capital investment, manufacturing method, and institutional factors. Projects were again categorized based on the manufacturing process area to be addressed. Further analysis of projects included a discounted present value calculation of project cost and direct savings when projected over applicable Navy procurements. A ranking of projects by savings minus investment and by savings to investment ratio was made. A technical evaluation dealing with project feasibility and risk was provided for the initial set of 101 projects.

2.6 COST DRIVER IDENTIFICATION

Contrast between the product and the process cost factors allows identification of generic cost drivers. In its simplest form, the two levels form rows and columns of a matrix, and the cost drivers are the highest cost impact areas or elements of the matrix. Examples of projects responsive to cost drivers are given in Section 3.2.

MANUFACTURING TECHNOLOGY STUDY

2.7 RATING OF INITIAL PROJECT SET

An initial set of 101 projects was analyzed by a computer program (NEMTA) for present value investment, direct savings, gain (savings-investment), and savings to investment ratio (return). Ratings of the candidate projects by highest gain were provided in several ways - highest absolute gain, highest gain in a particular cost category or in a particular weapon system, etc. Ratings are based on 4-year project savings conservatively applied to the appropriate electronics procurement. Scatter plotting of savings to investment ratio versus gain indicated that there was a correlation between the variables. A technique to eliminate the lowest projects (on an S/I basis) improves the return of the group considerably. There may be indirect cost savings that argue for retention of certain low S/I projects, however.

2.8 SUMMARY OF WORK ACCOMPLISHED

In the following table the key accomplishments of the tasks are described briefly.

Table 3. MT Study Task Accomplishments

Task	Key Accomplishments
A	Reviewed over 200 reports selected after an initial computer based data search. Reviewed the Tri-Service MT programs including 300 proposals that were presented at the Army ECOM Conference.
B,C	Interviewed 58 Navy and industrial project managers.
D	Performed an analysis that identified the 11 highest cost areas in electronics procurement.
E,F	Prepared a plan for about 100 project elements over a 2-year period FY80-81 and rated the projects according to savings and return on investment. Offered suggestions as to improvement of this plan and to extensions to FY82-84.
G	Documented results in a 3-volume final report.

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Section 3

RATIONALE OF THE NAVY MT PLAN FOR ELECTRONICS

3.1 IDENTIFICATION OF ELECTRONICS COST FACTORS

The approach used in this study identified two distinct levels of cost factors that are defined and ranked in Table 4. These are the level of product- and the level of process-associated costs.

By use of the top-down cost analysis with breakout of percentage costs at all appropriate steps, an average product cost breakout for Navy electronics systems is obtained and shown in Table 4a. The statistical errors on the average product breakout are slightly greater than 10 percent of the product value (i.e., cabinets $13.5\% \pm 1.5\%$, etc.) Data for about 100 electronic systems were analyzed to form these averages (Volume III, Appendix E).

A summary of the manufacturing process factors, which represents a supplemental way to view cost components, is shown in Table 4b. The process-related factors are apportioned into four parts, each of which impact the final manufacturing costs (production, capital expenditure, manufacturing methods, and institutional policy). The process-related factors are not presently amenable to a percentile quantification as specific as that for product factors. They are, however, listed in priority rank from top to bottom. This ranking order was based on the results of economic analysis, the industrial judgment offered during the series of study interviews, and the recent Army Conference (Vol. III, Appendix D). Illustrative areas under each process factor which contribute to the cost are listed. For example, the problems of low volume production and of requirement for the strict military documentation are both major contributors to procurement costs.

Some results can be drawn immediately from this method of ranking, e.g.: a) Labor at both the prime and subcontractor level amounts to about 70 to 80 percent of the procurement costs of Navy electronics; b) Various low technology material items such as cabinets and cables can cost more on a percent basis than high technology items such as integrated circuits;

Table 4a. Product-Related Cost Factors*

PRIME CONTRACTOR		TYPICAL SUBCONTRACTOR DISTRIBUTION	
Materials, components (often subcontracted)			
1. Cabinets, cables, interconnects	13.3%	1. Raw material	50%
2. Sensors, antennas, special tubes	13.3%	2. Labor	
3. Integrated circuits	8.0%	a. fab/assembly	24%
4. Small hardware, PCB, connectors	8.0%	b. test/support	26%
5. Discrete semiconductors	4.0%	Total	100%
6. Hybrid circuits	2.4%		
7. Passive components	2.0%		
	51%		
Subtotal			
Labor			
8. Assembly	15%		
9. Fabrication	11%		
10. Support	13%		
11. Test	10%		
	49%		
Subtotal			
Non-hardware costs			
Software	5-15%		
Systems integration	5-10%		
Shipping containers	2-10%		
Documentation	10-15%		
	22-50% over & above hardware costs		

*cf Vol. III, Appendix E for analysis of cost breakdown. All percents refer to total Hardware Costs.

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Table 4b. Process-Related Cost Factors

PROCESS*

1. Production, i.e., volume and continuity
2. Capital Expenditure, i.e., machinery for fabrication, assembly and test
3. Manufacturing Methods, i.e., design, fabrication, assembly and test
4. Institutional, i.e., depreciation and pricing policies

*Ranked in order of decreasing impact on reducing procurement costs (cf. Vol. III, Appendix E for further discussion)

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c) On some systems, software costs on the order of 30 percent of hardware costs were noted; d) Increasing volume and improving capital equipment availability may have a large impact on costs. All these areas represent opportunities to reduce costs.

3.2 PRIORITIES IN A MATRIX OF PRODUCT AND PROCESS FACTORS

During the course of the study valuable insight was provided by reviewing the suggested MT projects in a matrix relating to the product and process factors of the candidate project. Further, a matrix display of process-related factors versus product-related factors makes a map upon which to chart the overall MT program development. Table 5 indicates the number of projects in each matrix element. Two matrices are shown; the top (#1) displays projects concerning material and the bottom (#2) displays projects concerning system labor. If the rankings from high to low are observed, then the projects represented in the upper left area of each matrix ought to have a higher impact on manufacturing costs, while those in the lower right a lesser. This ranking scheme is only approximate because it does not quantify elements of the matrix that may have a disproportionately high potential for cost savings. Projects in some elements may offer a higher than average savings because of a previous inattention to cost savings, or a technological breakthrough.

The following exemplify how MT projects actually correspond to the specific intersections on the matrix in Table 5.

<u>Process</u>	<u>Product</u>	<u>Example</u>
Production Volume	Materials	Demonstration of the economic benefits of purchasing commercial components rather than special orders, i.e., cabinets.
Capital	Testing Labor	Purchase and demonstrate the worth of an automated test system, i.e., antenna pattern mapping.
Manufacturing Methods	Assembly Labor	Application of innovative tactile sensors used with feedback control for automatic parts insertion on PCB's.
Institutional	Assembly Labor	Demonstration of the economic benefit of faster depreciation of new manufacturing equipment on a military production line.

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Table 5. Matrix Display of 99 Candidate MT Projects Reviewed

PRODUCT FACTORS	PROCESS FACTORS				TOTAL
	1. Production	2. Capital	3. Mfg. Methods	4. Institutional	
Purchased Materials					
1. Cables and Cabinets	1	3	8	-	12
2. Sensors, Special Tubes	2	2	10	-	14
3. Integrated Circuits	3	-	6	1	10
4. Small Hardware, PCB's	-	1	10	-	11
5. Discrete S.C.	-	-	5	-	5
6. Hybrid Circuits	1	5	2	1	9
7. Passive Components	-	-	4	-	4
Labor, Final System					
8. Assembly	-	4	5	3	12
9. Fabrication	-	2	3	-	5
10. Support	1	4	1	-	6
11. Test	-	6	4	1	11
TOTAL Number of Projects	8	27	58	6	99

{ 1 }

{ 2 }

Note: The numbers in the rows and columns in the matrix refer to the number of projects reviewed, a total of 99.

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Some of these projects go beyond the present scope of MT within the Navy; however, the cost reduction goals of MT may be well served by including projects in the newer areas.

Table 5 is a graphic summary that contrasts the areas of process and product costs factors with the number of candidate industrial proposals received and reviewed during this study. In the process areas the manufacturing methods and capital equipment are well represented, but there are fewer good suggestions in the production volume and institutional cost factor areas. The distribution across the product cost factors is relatively uniform and variations are not statistically significant. The Navy can be selective in areas rich in proposals (e.g., category #4, Sensors and PCB's, and #3, Manufacturing Methods, each had 10 proposals) and eliminate weaker proposals or consider multiple funding of these projects to reduce risk. The areas with an obvious dearth of proposals should be scrutinized to identify possible opportunities where industry might consider alternative ways to lower electronics costs. Spreading projects over a wider number of areas increases the probability of finding at least one key cost saving technique. Techniques illustrated by successful MT projects can then be exploited for additional cost savings.

3.3 ECONOMIC AND TECHNICAL RATING

The set of 101 candidate projects was rated on the basis of ~~discounted savings, discounted saving over discounted investment ratio,~~ and technical risk. A compound discount factor of 10 percent was used to account for cost of money, and an inflation rate of 4 percent was assumed. Project rankings were only slightly sensitive to these assumptions. Overall technical risk was evaluated: When there had been previous project demonstration or when techniques had been used successfully in another industry the technical risk was rated low. When cost savings opportunity competed with different approaches or when there had been little or no preliminary work technical risk was rated high. The best estimated percentage savings (usually supplied by industry) were reduced as follows: 90 percent

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if low, 50 percent if medium, 25 percent if high risk. Two calculations were performed and reported: Best estimate, and risk-adjusted estimate.

It was determined that elimination of the projects with the lowest savings minus investment dramatically improved the program savings to investment ratio. Analysis of the detailed distribution of project savings indicated a cut eliminating the lowest 20 percent of the projects increased savings to investment by 20 percent. It is recommended that these low S/I projects be reevaluated particularly as to indirect cost benefits.

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Section 4

SUMMARY OF THE 5-YEAR MT PLAN

The plan outlined here is a first attempt to define the required Navy Electronics MT budget in the fiscal years FY80 to FY84. The SAI study team was tasked to provide for an expenditure constrained to approximately 20M/year over a 5-year timeframe, as an example of the methodology being developed. Exercising the techniques developed here may justify a larger program eventually. One word of caution: The plan laid out provides a framework to classify and rate industrial proposals, to achieve program balance, and, potentially, to diminish risk. The reader should recall that the next step - a response from industry with detailed cost data and improved technology ideas - has not yet been taken. Furthermore, it is to be expected that the plan would be subject to revisions as future procurement estimates become firm and other state-of-the-art projects evolve.

4.1 THE FY80-81 ELECTRONICS MT PLAN

The 101 candidate projects were evaluated as to cost and return, as outlined in Section 3.3. The cut on low S/I was applied as described in Section 3.3, and Appendix II.

The effect of the cut was that the sample was reduced from 101 to 78 projects, program costs were reduced from 36M to 31M present value costs, and S/I was increased from 18 to 22 on a 4-year basis for cost savings. Average project cost was 401K. Because some of the low S/I projects may have important indirect cost savings, further analysis is recommended before final project selection.

The final 78 candidate projects were evaluated as to cost and savings (and their ratio) in relation to the product area costs. Overall averages were 0.2 percent for project cost to product area cost, and 4.4 percent for project savings to product area cost. Overall S/I was 22 (refer to Table 6).

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Table 6. Project Rating vs. Product Cost Area Impact

Product Cost Area (i)	Relative Project Ratings in Product Cost Areas		Relative Cost Savings $\frac{(\text{Savings } \%)_i}{\langle \text{Savings } \% \rangle}$	Recommended Redistribution of Project Allocation to Improve Savings	
	$\frac{(S/I)_i}{\langle S/I \rangle}$	$\frac{(\text{Cost } \%)_i}{\langle \text{Cost } \% \rangle}$		Increase Funding	Increase Quality Projects (i)
1. Cables & Cabinets	1.7	1.1	1.9	✓	✓
2. Sensors, Special Tubes	0.3	0.3	>0.1	✓	
3. Integrated Circuits	0.8	2.4	1.9		✓
4. Small Hardware, PCB's	1.3	0.9	1.2		✓
5. Discrete S.C.	0.1	2.3	0.2	✓	✓
6. Hybrid Circuits	0.8	3.3	2.6		✓
7. Passive Components	>0.1	1.8	0.2	✓	✓
8. Assembly	0.5	1.1	0.6	✓	✓
9. Fabrication	0.5	0.2	0.1	✓	✓
10. Support	0.8	0.7	0.6	✓	
11. Test	5.0	0.5	2.5	✓	✓

Note: For all electronics procurement we define =

$$\frac{\text{Project Cost } X \ 100}{\text{Procurement Costs}} = \langle \text{Cost } \% \rangle = 0.2\% \quad \frac{\text{Project Savings } X \ 100}{\text{Procurement Costs}} = \langle \text{Savings } \% \rangle = 4.4\% \quad \frac{\text{Project Savings}}{\text{Project Cost}} = \langle S/I \rangle = 22$$

and for each product cost category (i) we define =

$$\frac{(\text{Project Cost})_i \ X \ 100}{(\text{Procurement Cost})_i} = (\text{Cost } \%)_i \quad \frac{(\text{Savings})_i \ X \ 100}{(\text{Procurement Costs})_i} = (\text{Savings } \%)_i \quad \frac{(\text{Project Savings})_i}{(\text{Project Cost})_i} = (S/I)_i$$

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4.2 IMPROVEMENTS TO THE FY80-81 ELECTRONICS MT PLAN

Based on the imbalances seen in the product area ratings and the overall percentage savings several improvements are suggested. Most importantly the number and quality of the projects need to be improved. The set of 78 projects with a present-value cost of 31M needs to be expanded considerably. The figures argue for a much higher commitment for MT projects, i.e., an investment of 1 percent of procurement cost in MT projects would yield 15 to 20 percent in cost savings on a 4-year basis. Specific areas where current plans could be improved are given in Table 6 which shows a rating of projects versus product area averages. Considerable imbalance is evident in S/I, project cost, and savings. In the table, the indicated recommendations depend on the project rating. In project areas with high S/I (e.g., Category #1, Cabinets and Cabling) increased funding is recommended to achieve higher savings. Category #3, Integrated Circuits, has nearly three times the value of projects as the average area while returns are below average. Opportunities to further improve or redirect the projects exist. Fabrication Labor, Category #9, is low in relative savings to investment ratio. Again, this suggests that opportunities exist for more innovative approaches since few MT projects were received in this area.

The reader is encouraged to review the other categories in a similar way. Such a review points up the specific areas where there is room for both a quantity and quality improvement in the FY80-81 plan. Follow-up visits to industry and peer review of the candidate projects will provide more specific suggestions as to how this can be accomplished.

4.3 SUGGESTIONS REGARDING THE FY82-84 TIME PERIOD

Uncertainties in procurements and in technologies extrapolated five or more years in the future make specific project recommendations for the

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FY82-84 time period difficult. While the lessons learned from the success of the MT program in the period preceding FY82 will dominate program planning in FY82-84, industrial and military views on the key features in these out-year plans relate largely to the incentive area. In one utopian view industry should be implementing MT on its own initiative without the review and direct funding of government for specific projects. Internal MT program fundings similar to that of the internal R&D programs now allowed under government contracts was a suggested possibility. Manufacturing firms are interested in interchanging information on manufacturing processes, and proprietary barriers are not viewed as a major impediment to this exchange. One way to facilitate industrial interchange is to create working groups of manufacturing firms focussed on topical areas. Vertical organization of the working groups (to include prime and subcontractors, material suppliers, manufacturing machinery and test instrument makers) stimulates interchange of ideas and diffusion of technology. Standardization of automation procedures - CAD/CAM software interfaces, robotic control program languages and the like - is another desirable goal. Appendix B, Volume III presents more specific suggestions about stimulating incentives.

Indirect cost savings were not explicitly calculated in this study. An indirect cost savings results when the reduction of weight, power consumption, cooling, enclosure requirement, or other support function allows the redesign of the complete weapon system for lower costs. Improved electronic reliability will decrease life cycle costs both of the electronic systems and the platform. Particularly in the FY82-84 period larger overall savings will result from MT projects (begun earlier) directed at these specific goals as well as lowered procurement costs. Recommendations for improved avionics manufacture for integration with the V/STOL aircraft were received as an example. The study team could not devote enough effort to fully justify indirect savings for projects during the period of the study. This area ought to have high priority for further investigation.

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Section 5

CONCLUSIONS

5.1 GENERAL CONCLUSIONS

Electronics costs amounting to about 10 to 12B annually represent 30 percent on the average of the cost of DoD weapons systems. Costs of electronics on a functional basis, however, are constantly decreasing because of a volatile, evolving technology base. The DoD represents a major segment (about one-fourth) of the electronics industry market and as such can exercise considerable leverage. Improved commercial practices are not uniformly applied nor is the implementation of advanced manufacturing technology uniformly evident in the military electronics systems industry. Electronics MT therefore represents a prime mechanism for cost reduction. If given the proper incentives, industrial representatives have indicated a willingness to make manufacturing improvements that will be of benefit to the Navy. Many of the specific suggestions advanced during the interviews with industrial program managers are reflected in the recommended 5-year plan.

In addition, advantage should be taken of the following trends that can also contribute to efforts to reduce electronics costs:

- Mass consumption requirements for commercial systems create a favorable market structure justifying large capital expenditure on efficient production equipment. However, the specialized nature of the DoD market mitigates against the benefits that commercial buyers are obtaining.
- Improvements stemming from an increasing volume of commercial electronic systems include more reliability, ruggedness, and greatly improved performance as well as dramatically lower costs than a few years ago.

The Navy can benefit from these two trends by encouraging those firms who produce military electronics to develop improved manufacturing technology and by using commercial items where performance complies with acceptable standards.

There is a widespread feeling among Navy contractors that successful implementation would be facilitated by overcoming a number of institutional

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disincentives to manufacturing changes. These disincentives include the technical risk, the uncertain span of procurement, the yearly contract re-negotiation cycle, and the limits on equipment write-off periods. In two areas, those identified in Table 4b as production and institutional process factors, there seems to be considerable potential for expanded effort. These factors may or may not be considered MT in the traditional sense, but it is recommended that the Navy MT office explore the possibility of funding in these areas because of the large potential payoff, particularly in the FY82-84 timeframe.

This study has verified that manufacturing technology can have an average cost impact of up to 20 times in the procurement of Navy electronic systems. The study has identified and quantified a number of areas where programs can be implemented over a 5-year timeframe with significant economic benefit to the Navy. Innovative procedures have also been developed to analyze the MT program.

The study has identified feasibility work in manufacturing methods as the current emphasis of MT work. The study results confirm, however, that development and implementation work has high benefit, and is needed to further the goals of the MT program, i.e., to reduce Navy weapons systems costs.

Another major realization that surfaced during the analysis dealt with the complexity of the industrial infrastructure. Firms can and do operate on several levels of activity that are directed toward providing the Navy with weapons systems. Many firms are vertically integrated, but usually with separate "cost centers" that are often managed relatively independently. The study shows that the bulk of present MT projects are sponsored by all three services at the "subcontractor task level." This means that most projects are directed at generic electronics manufacture at a fairly low level of integrating, e.g., hybrid circuit assembly, or printed circuit board (PCB) preparation. Too little emphasis is paid to final assembly and system test.

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A major recommendation resulting from the study is to broaden the industrial participation and to include more prime contractor tasks such as final assembly and testing. It is also desirable to encourage more participation of manufacturing equipment manufacturers and this could be accomplished by a team arrangement with a prime contractor. The equipment manufacturers can expedite the diffusion of MT to a number of firms through their normal business activities.

Some low technology material areas (such as cabinets) and most labor areas (assembly, electronics testing, etc.) represent opportunities for improved projects and increased MT funding. Industry needs rapid decisions on its MT suggestions if it is to be fully responsive to the Navy program needs. A final and important point is that industrial incentives need to be identified and implemented to promote a better quality MT program (Appendix B, Vol. III). Where these types of activities could be worked into an MT project description they are included in specific project recommendations (Appendix A, Vol. III).

About 400 candidate projects were received and reviewed; the final set of 101 represents about a 25 percent acceptance ratio. Projects were rejected or deferred because of inadequate information, low technical rating, or low savings to investment ratio. Ninety percent of the firms interviewed responded with either cost breakout or project data in the fairly short response time allowed.

5.2 SPECIFIC FINDINGS

The following six specific findings resulted from the performance of this study.

- 1) A first attempt to lay out a plan for electronics MT in the FY80-81 timeframe resulted in 78 projects (31M present cost value) with an average savings to investment ratio of 22. The savings are calculated over a 4-year period and assume project success and implementation in applicable weapons system procurement after project completion. Considerable breadth exists in the plan leading to lower risk. In addition opportunity exists to multiple fund leading projects.

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2) The MT plan described above projects a direct savings of about 4.4 percent in electronics procurement over a 4-year period. Some improvement in projects can be anticipated as a result of further industrial review and response with more detailed proposals; however, it seems clear that a considerably larger program (perhaps 3 to 5 times as large) is warranted. At this time the point of diminishing returns is unknown. For some cost critical weapons programs, estimated savings on the order of 5 percent may make the difference on a project go-ahead. In other instances, much larger savings need to be realized for MT programs to have a major impact. These can be achieved if larger funding amounts are authorized. At present the MT program is relatively new and few projects have actually been shown to be successful. By the FY80 timeframe, however, any success of earlier years can motivate increased expenditure.

3) Improvements in the FY80-81 plan are possible and perhaps desirable. Electronics costs are labor intensive. A top-down analysis of electronics costs indicates that a total of 70 to 80 percent is allocated to assembly, support and test labor at the prime and subcontractor level. The candidate projects ratings indicate that improved projects and more funding is needed in most labor areas. A low technology area such as electronic cabinets, cable harnessing, power sources and conditioners shows up as a high cost area. In this case inattention to cost-effective practice may be the root cause. Opportunities to procure commercial quality cabinets or to design and innovatively manufacture low cost military cabinets appear bright. Recommended programs also include more automation of cable harnessing work, and investigation of improved cable terminations. Interchange of these ideas with industry ought to be a high priority item in order to increase the quality and number of candidate projects.

4) The Electronics MT Plan for FY82-84 should continue to emphasize reduction of labor content in manufacture. This infers that the MT plan must adequately represent work in robotics, especially that geared to handle delicate operations in confined environments. This in turn requires work with tactile and visual sensors for manipulator feedback control. Integrated manufacture, combining computer-aided design and computer-aided manufacture should be attempted on a demonstration basis.

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The primary leverage available to the MT program lies in offering incentives to industry to wholly or partially implement these changes themselves. Improved benefit to the Navy during this timeframe will come from MT projects addressing the indirect cost savings available in advanced weapons system designs. Examples of projects of this type include lighter weight, reduced power consumption electronics units for advanced aircraft and helicopters, and more energy efficient manufacturing processes.

5) Non-hardware areas such as software development, and documentation of equipment are costly (up to one-half again of hardware costs on the average). Experimental efforts address the use of computers themselves to help write software, and to prepare documentation.

6) Many opportunities for cost savings and program risk avoidance have been identified. To meet the goals of reduced weapons systems procurement costs, present and future MT programs need to be tied closely to relevant weapons systems. More MT projects ought to relate to prime contractor tasks, e.g., final system testing. This assures that there is a user system for the technology, and speeds up the dissemination of the technology. The funds spent in diffusion could be more generously cost shared by industry to reduce the financial drain on the Navy MT program.

Maintaining healthy industrial cooperation should be a prime goal of the Navy MT program, since such cooperation enhances the success of the MT program in all phases of production. Procedural activities such as rapid program definition dissemination and rapid decisions on proposals will help. The Navy MT program office should consider multiple funding of proposals from industries (with differing technical approach) in important problem areas as another key way to reduce risk.

Another useful tactic is to form industrial groups for joint interchange of technical data about an MT project area. The Navy could issue an RFP to industry for exploratory and implementation work in one problem area. The best proposals ought to be fully funded. Other firms with a high technical interest ought to be given small contracts allowing their technical people to visit the projects in progress and subsequently to review

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demonstrations and implementations of the approaches discovered. Vertical as well as horizontal components of special working groups would allow participation of manufacturing equipment manufacturers.

5.3 EPILOGUE

No study of a dynamic area such as manufacturing technology can ever really be complete. A methodology and framework upon which to display and expand the Navy MT program in the area of electronics has been put forth. The plan reported here will be useful to the Navy and industry if it is updated periodically as new data are available. New procurement requirements, better estimates of manufacturing costs, and innovative proposed MT suggestions will emerge over time. The computer based analysis of the program plan can and should be updated as appropriate.

The highest impact of this work will come from increasing the Navy's contact with industry in the area of MT. A follow-up briefing to the cooperating firms and plant tours for the benefit of the Navy MT representatives seems in order. This could be followed by a summary working group meeting to go over proposed projects and encourage or exchange ideas. This type of thorough interaction and follow-up with industry ought to encourage better and more cost saving MT proposals in the electronics area.

Further work needs to be done to develop and quantify the 5-year plan. More industrial cost data, much of which have been promised as a result of the interviews, need to be included. Areas where data are weak have also been identified and will be followed up.

The study team was left with the overall strong impression that industry is ready and willing to respond vigorously to the needs for lowered electronics costs. The Navy needs to follow up on this response to maximize the benefit available.

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Request for Additional Information

Volume II of this report is the candidate five-year budget plan for Navy Electronics Manufacturing Technology. Volume III contains detailed appendices concerning the study methodology. Interested readers may obtain copies through Department of Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

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