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FORECAST FOR MILITARY SYSTEMS USING ELECTRONIC DIGITAL COMPUTERS

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FORECAST FOR MILITARY SYSTEMS USING ELECTRONIC DIGITAL COMPUTERS

Report L-3

Jay W. Forrester, Chairman
Hugh R. Boyd
Robert R. Everett
Harris Fahnestock
Robert A. Nelson

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS
Project DIC 6345

September 17, 1948

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OFFICE OF THE PRESIDENT

September 8, 1948

Mr. N. McL. Sage, Director
D.I.C.

Dear Mr. Sage:

From time to time I hear about military and other governmental agencies which are laying more or less definite plans to utilize high speed digital computers. These interests include control of guided missiles, integrated radar networks, fire control, cryptography, air traffic control, and others.

Both because of M.I.T.'s responsibility for the Whirlwind Project and also because of my association with several advisory groups to the Armed Services, I am concerned that we have as clear a picture as can now be presented regarding the potentialities for useful applications inherent in such a device, and also the time, money and staff which will be required to carry digital computing equipment to the point of use by the Armed Services.

It is realized that any estimates which can be made at this time may be subject to substantial modification with later experience, but nevertheless I think it is very important for us, for the Office of Naval Research, and for the various agencies which are contemplating use of the digital computer to have clearly in mind the best estimates which can now be made with reference to the cost, the time schedule and the technical possibilities involved.

Will you please, therefore, with the best technical advice available, prepare a brief report in answer to these questions? I believe that this report should also be made available to and discussed with the Chief of Naval Research and any others importantly concerned with this project whom you and he may feel it desirable to include for purposes of information or advice.

Very sincerely yours

Karl T. Compton
President

KTC/L

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DIVISION OF INDUSTRIAL COÖPERATION
CAMBRIDGE 39, MASS.

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ASSISTANT

September 17, 1948

Dr. Karl T. Compton
Room 3-208
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Dr. Compton:

The attached report is submitted in answer to your request of September 8 for information on the position of digital computers in the national research and development program. The staff of Project Whirlwind has been concerned for many months about the issues raised in your letter. As they became more immersed in the digital computer, which is a part of their program, the more aware they became of the broad utility of digital computers as a tool and of the considerable magnitude of a larger program of applying them to the general military situation.

For this reason they have been accumulating for some months a background of information through visits and exchange of information with commercial and military laboratories working on digital equipment and its possible applications. They had made some progress in an analysis of all the information in their possession. After much consideration it seemed to me that a quick answer from this group might be more useful to you than one three to six months from now in which more individuals had participated. For this reason, Mr. Forrester and his staff assembled the attached report from material at hand. I requested, if possible, a presentation on one chart covering the elements of staff, dollars, and time as well as the specific areas in which they believe the digital equipment useful and worth considering taking into account its performance and economies in use of manpower.

Very truly yours,

N. McL. Sage

N. McL. Sage

ABSTRACT

Many plans are now being considered for the military use of information systems built around electronic digital computers. Such systems appear unique in their ability to process and evaluate information sufficiently rapidly for modern high-speed military operations. The advantages gained when digital information systems make possible the better integration and more effective use of other military equipment should more than justify the diversion of men and resources to digital information system development.

(5)

An approximate estimate has been made of the time and cost to bring such information systems to useful military realization. This forecast shows a period of fifteen years and a research and development cost, including field testing and trial operation, of two billion dollars ($2,000,000,000) to bring these systems to an operational status. An equal or greater production program would follow for equipping the Military Services with production equipment. Compensating adjustments in completion time and total cost can be made to meet military necessity.

Such a program would require an active training plan to provide necessary personnel.

An initial investigation requiring four years and sixty-five million dollars ($65,000,000) would provide the necessary information on which the importance and feasibility of the complete program could be judged.

FORECAST FOR MILITARY SYSTEMS USING ELECTRONIC DIGITAL COMPUTERS

Description and Military Applications:

As used in this report, the term "Electronic Digital Computers" describes a combination of information storage and switching systems capable of performing selection and choice operations in addition to the basic operations of arithmetic. In general, the equipment is that capable of operating in the range of 1,000 to 50,000 such arithmetic and switching operations per second.

Despite its popular reputation, the digital computer does not have human thinking intelligence, but it does have superhuman computing speed, and, when properly directed (viz., fed input information correctly and programmed correctly to describe the desired operations), the output gives orders or information which can be either automatically transformed into action or interpreted by humans for further processing. There need be no human link in this computing chain. Comparatively speaking, the time element for equipment to respond is seconds or minutes compared with days, weeks, or sometimes months using presently available methods.

This speed makes it highly suited to the problems of combat operations. In the future these, to be successful, seem geared to a vast increase in information that must be analyzed and reduced to a usable form before the time for use has expired.

Present art makes it reasonable that men can be trained in the use of digital computer systems; that the systems can be produced, field tested and integrated into the military services with a saving of manpower; and that the increased accuracy of output information can enormously extend the types of problems capable of solution, in time to use the results.

By more effective use of available information and intelligence, the digital equipment will make its contribution not only at the battlefront, but also in the supporting activities of logistics, design, information centers, etc.

Digital equipment can contribute in many diverse activities requiring differing types and mobilities of design. To provide equipment for the full breadth of possible applications is an undertaking which appears greater than the magnitude of radar.

The use of digital information systems may eventually result in improved types and simplifications of other military equipment, and these economies may much more than pay the cost of a long-range digital equipment development program. The men and resources for such work would, therefore, be compensated by those eventually released from other pursuits as they were proved less promising.

In making the estimate here reported, it has been assumed that digital equipments for the applications now being considered (see Column 2, Figure 6) are to be made available as soon as possible, compatible with effective use of technical personnel.

The report covers not only digital computers, which are a small part of the total, but, in addition, the complete systems of which the digital computer is only a nucleus. The program includes auxiliary equipment, applications studies, field tests, and training of staff required to do research and to produce and operate the equipment.

The potential contribution of digital computers to the military effort can hardly be overestimated. As control devices, digital information processing equipment can provide services promised by no other equipment. Even in present initial designs now being constructed, efficiencies (in terms of computation per dollar's worth of equipment) will be ten to several hundred times present analog equipment. Space and weight reductions in proportion to these efficiency increases can be realized. For many operational problems in the offensive use of and defense against guided missiles, aircraft, and submarines, the digital equipment at this time seems to be alone in promising the required capacity, speed and economy.

An example of a requirement in the solution of tactical problems is found in the interception of supersonic missiles. Here there is need for combined computer and control system which can:

1) Automatically receive radar and other information from multiple locations,

2) Correlate this with past information,

3) Distinguish between types of missiles and distinguish missiles from aircraft based on identifying information and trajectories,

4) Predict trajectories to the impact point (if flight is uncontrolled),

5) Assess possible damage and importance of defense action to permit concentration of defense against the most dangerous missiles,

6) Take rapid automatic defensive action in selecting launching location and firing defensive missiles, where time is too short for human intervention,

7) Carry on these operations with a minimum of equipment,

8) Possess the required flexibility to avoid the need for redesigning to meet changing tactical situations and the appearance of new weapons of either offense or defense.

No equipment at present in use can accomplish these requirements in the interception time likely to be available. Digital computing systems appear capable of accomplishing the task.

Applications are foreseen in most branches of the national and military economy--air traffic control, integrated fire control and combat information centers, interception networks, scientific and engineering research, guided missile offense and defense, and data processing in logistics.

RESEARCH AND DEVELOPMENT:

A forecast of the problem ahead shows that equipment for engineering and scientific use, fixed location interception and air traffic networks, simulation and synthetic training, semi-mobile, mobile, and airborne equipments, and applications to logistical calculations, are all part of the problem. The cost of making this equipment available to the Military Establishment sometimes appears to be much underestimated because of linear extrapolation of past laboratory programs. Historically, similar developments have grown exponentially; and the nearest parallel is found in the easier problem of bringing radar to an operational status.

Unfortunately, groups relying on use of high speed digital computers in 1949, 1950 and 1951 have believed that such equipment would be ready for their scheduled requirements, and that the apparatus would be on the shelf ready for incorporation in their programs. With the present scope of effort on the problem no such happy situation exists, because the systems appear to be more complex than radar, are likely to be used more widely, and their integration with other facilities are more time consuming. Digital computers in 1948, with respect to their ultimate capabilities, are in about the position of radar in 1937. Figure 1 compares the evolution of radar with the probable evolution of digital computers. In relating radar to the present status of digital computers the revolutionary appearance of the high power cavity magnetron in radar is similar to the entry of high capacity storage devices into the computer field. Most promising of these at present is the electrostatic storage tube, the status of which now compares with the magnetron just prior to World War II.

Information collecting systems will be set up and used with a combination of present day mechanical,electrical, and human computers, until a better substitute is developed. There is danger of misinterpretation in discussing the costs of information systems using digital computing mechanisms. Of these system costs, only a small part are for digital computers themselves, the remainder going into training, applications studies, field testing and auxiliary equipment. If there is to be expansion in information collecting systems, the costs of training, applications studies, etc., must be met regardless of the method used in the reduction and processing of the information. Digital computers as a working tool should be evaluated on what they promise in comparison to alternate ways of getting a comparable result.

Figure 6 lists as activities (Column 2) the areas of utility of computer systems covered in this report. Beginning with these applications as a base, annual manpower estimates for each activity were allocated to the 75 subdivisions of effort into which, for convenience, the whole program was divided. For example, the subdivisions for line 5, Fixed Location Control Systems were:

Applications Studies
Experimental Design
Experimental Construction
Auxiliary Equipment Design
Operation of Prototype and Study Systems
Installation
Field Testing
Prototype Design
Prototype Construction
Production Design
Production Supervision

In Basic Research (line 1, Figure 6) the subdivisions were:

Mathematics
Storage Tubes
Magnetic Storage
Delay Storage
Basic Storage Research (new methods)
Component Research
Component Development
Circuit Theory
Circuit Development

It is helpful to have a cost estimate even though the uncertainties of time required to develop essential elements, lack of adequate studies on methods of application, and relatively little knowledge of the plans of those responsible for national defense, make such an estimate a forecast rather than a factual presentation. Our figures of total cost should be accepted as a warning rather than as a budget.

This cost and use of personnel need not be in addition to other programs if the possible higher efficiencies obtainable by combining digital equipment with radar, guided missiles, interception networks, and fire control equipment can be demonstrated at an early date. The personnel and money otherwise needed in the latter programs can be redirected. For example, the radar burden will be reduced when digital equipment simplifies the radar-search-target-acquisition-fire-control triangle. The substitution of digital equipment in the precision fire control field should release space and weight in military equipment, and money and men in the national economy. Therefore, only part of the men and materials cost in this estimate are a burden above presently planned national activity.

CONCLUSIONS:

A summation of the available data leads to the following:

A. To provide at an early date information necessary to properly judge the importance and feasibility of digital computer systems to national defense, it is necessary to agressively support a research and development program covering the first four years of Figure 6. The cost of this work would be about sixty-five million dollars ($65,000,000) which is moderate compared to the magnitude of several billion dollars for the entire program.

B. To provide digital computers and control systems for the Military Establishment as outlined may require fifteen years and two billion dollars ($2,000,000,000) to bring the first production equipment into useful military operational control systems. Figure 2 shows yearly expenditures and the breakdown into (1) research, development, and training, (2) applications studies and field tests, and (3) the cost of production equipment.

C. A training program is needed immediately to provide manpower even for the initial four-year period. If the ultimate program develops along the lines of Figure 6, this training activity would grow to a level of 4500 persons per annum in fifteen years. Such a training level would build up a research and development staff of 7500, provide replacements to that staff, and supply the trained technical operators and supervisors of military equipment.

D. If the present military situation dictates the need for digital information processing equipment at an earlier date than shown in this estimate, a reasonable acceleration can be obtained by accepting less efficient use of personnel with resulting higher costs. An estimate of this total-cost versus time relationship is given in Appendix E. Further acceleration, or reduction of total cost, would require narrowing the field of digital equipment application.

E. The production cost of equipping the Military Establishment beyond the fifteen-year period for wartime operation may be the order of magnitude of an additional two billion dollars ($2,000,000,000). This approximate estimate is based in part on radar in World War II and a table and discussion are given in Appendix C. It does not allow for applications beyond those in Figure 6.

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APPENDIX A: THE COST ESTIMATES:

The estimates assume a "normal" active peacetime military pace. Figure 5 (See Appendix D) shows this peacetime operating point on an estimated percent-total-cost versus percent-time curve. In contrast, radar development is assumed to have occurred at the point of one-third normal time and about three times normal total cost, meaning radar was developed at a yearly expenditure rate of nine times normal. In arriving at the estimates, the following costs are included:

1. Salaries of graduate student trainees assigned to computer instruction for one year.
2. The routine operating cost of several scientific and engineering high-speed computer traffic networks. This operating cost is about fifty per cent of the 15-year total of line 4 in Figure 6.
3. The cost of experimental and prototype models.
4. Field testing expenses of research and development groups.
5. Production designs.
6. A small percentage of the total production cost. The greater part of this cost will occur after the fifteen-year period covered.

The following costs are not included:

1. The required redesign of associated equipments; fire control, radar sets, guided missile telemetering systems,
2. The cost of auxiliary equipment not associated directly with computers and their immediate terminal facilities, nor in logistics the cost of input equipment for information collection,
3. Aircraft, ships, missiles, and military establishments used in field tests,
4. Communication channels or their rental for information transmission,

5. The setup and typing of engineering and scientific problems, except for training necessary personnel,

6. Governmental costs of coordination and administration,

7. The operation of production equipment after delivery to the military, except for the training of operators,

8. The major part of the required production. See Appendix C.

APPENDIX B: METHOD OF ESTABLISHING ESTIMATE:

The cost and time estimate of Figure 6 is based on:

1. The types of computer applications now under discussion.

2. The rate of progress of present computer development including Project Whirlwind at M.I.T. which is the most extensive digital computer project at the present time.

3. A detailed allocation of technical staff in each year to each of 75 subdivisions of work.

4. The research and development cost obtained by multiplying the number of staff by $20,000 per year to cover non-staff costs, material, service, and overhead. Staff must include all direct administrative persons or a higher rate must be used.

5. Educational costs obtained by multiplying teaching staff by $20,000 and each assigned student by $3,000 to cover staff and student salaries, equipment and facilities. This rate for staff to cover equipment, non-staff personnel, and overhead may be about twice the usual technical college operating cost. However, radar training was near this rate. The higher rate is used to cover new and special equipment required, the problem of setting up new courses of instruction, and the inefficiency inherent in a new and rapidly growing educational program. In the number of trainees, 20% of current technical staff were added for replacement purposes.

6. In addition to items 4 and 5, the estimated value of the required experimental, prototype, and some production equipment built in the fifteen-year period as shown in Figure 6.

7. The assumption that computers will perform their first useful services for engineering computation and that this work will be charged with some pioneering for the benefit of other applications.

8. A coordinated program operated with full information interchange.

9. The history of radar, which has here been used as a check to establish the reasonableness of the results of the estimate.

10. Field testing being a much more expensive and time-consuming problem than for radar because of the required elaborate interconnection with radar, microwave relay links, servomechanisms, and other information collecting and using devices.

11. The assumption that for production military systems, ten men with full technical training must accompany each million dollars worth of equipment.

12. The assumption that the logistics and simulation programs are largely ones of study and applications research. Computer development is covered in other programs, except for special terminal equipment and purchased computing devices. Production for actual logistics work will follow the fifteen years of this estimate.

These estimates include only specifically itemized activities and may be low to the extent of omissions.

APPENDIX C: PRODUCTION COST AFTER FIFTEEN YEARS:

The approximate order of magnitude of cost for production of digital information systems to equip the Military Establishment for wartime operation is based on the following table. Much of the table is derived from direct comparison with radar production. For shipboard installations, computer systems will be used in much smaller numbers than radar but will probably cost correspondingly more. Airborne figures are half that of radar in World War II. The list does not include probable military uses beyond those of Figure 6 nor commercial and industrial applications.

	Total Cost
Guided Missile Data Reduction	$ 25 million
High Speed Computer Traffic Networks (Engineering and Scientific)	30
Cryptographic	65
Interception Networks (Without radar or communications)	150
Air Traffic Control	150
Industrial Process Control (For strategic military applications)	50
Simulation and Training	125
Semi-Mobile-Shipboard (Same as large ship radar in World War II)	300
Mobile (Same as World War II radar)	175
Airborne (At 1/2 the World War II radar for navigation, guided missiles, fire control and search)	400
Logistics (Including automatic inventory control; estimate is only an order of magnitude until applications studies have been completed)	500
	$1,970 million

APPENDIX D: DISCUSSION OF DIAGRAMS:

Figure 1 is included to permit a comparison of the proposed digital equipment program and the corresponding history of radar. Corresponding milestones in radar and digital system development are obtained by matching in 1948 the status of computer storage devices with the status of radar magnetrons in the late 1930's.

Figure 2 is a smoothed curve obtained from the data in Figure 6. Total costs are divided into that for: (1) research, development and training, including experimental and prototype equipments, (2) Applications studies and field tests, and (3) production. Early production is in equipment for engineering computation and simulation. Production for military field equipment is appreciable only in the last three years. Applications and field tests represent a large part of the total because extensive integration of computer systems must take place with information gathering equipment such as radar and information using equipment such as aircraft, gun, and missile controllers.

Figure 3 is a smoothed curve derived from Figure 6 showing the total active staff at any one time, not including operators of military equipment. Technical staff has almost reached its maximum at the end of the fifteen-year period and if traced further could be expected to level out rapidly.

Figure 4 is a smoothed curve showing the staff it would be necessary to train each year to supply the program of Figure 6. Initially this technical personnel goes entirely into building up the scientific staff in research. This number will reduce as the total staff reaches its maximum. Later a large number of those trained are for replacements in research and development staff. In the last five years, training of technical persons in the use and operation of military equipment must keep pace with the production of such equipment.

The present, existing, 1948 level of training is much below the initial point of the curve and is a warning that an active research program might not be able to start until after a delay of one to three years to build up a teaching group.

Figure 5 is an estimate of the relationship between total cost of a research-development-production project and the time necessary for completion. One hundred per cent (100%) cost and one hundred per cent (100%) time is defined by the "normal active peacetime" level of working efficiency. The general shape of such a curve is fairly obvious. For a given project, there is a minimum below which the time cannot be reduced regardless of the total expenditure. Likewise, there is a minimum below which the total cost cannot be reduced regardless of the amount of time taken and the amount of care exercised. The exact values on the curves can only be estimates since they are subject to neither measurement nor experimental study. It should be noted that rate of expenditure varies as the quotient of total cost divided by time. Thus, for the point of 200% cost and 50% time the expenditure rate per year is four times normal. The estimates of Figure 6 are intended to represent a working efficiency described by the 100 per cent point in Figure 5. With sufficient prior planning, and so long as available personnel and resources are not exceeded, Figure 5 can be used to adjust the estimated program to a lengthened or shortened time schedule.

Figure 6 has been discussed. It was derived by allocating staff to 75 subdivisions of activity. The largest subdivisions accounted for approximately 400 staff. Costs were calculated from this assigned staff by the methods discussed in Appendix B.

APPENDIX E: ACCELERATION OF PROGRAM

Figure 2 shows a fifteen-year interval before substantial military production follows proven experimental and prototype models. This could be shortened somewhat using emergency action by omission of some steps, but at reduced efficiency as estimated in Figure 5 which is discussed in Appendix D.

Most significant is the observation, based on these assumptions, that the first several years can be accelerated, because of lower expenditure rates, with much less total cost than a corresponding acceleration of the last several years. Two alternate methods of reducing the fifteen-year program to eleven years follow:

> From Figure 5, acceleration to 60 per cent of normal time raises total cost to 170% of normal or results in a cost increment chargeable to the acceleration of 70 per cent.
>
> From Figure 6 the total cost of the first 10 years of the 15 years is $583 million and the cost of the last 10 years is $1931 million. Multiplying by 70 per cent there results:

Extra cost of reducing the <u>first</u> 10 years to 6 years	$ 410,000,000.
Extra cost of reducing the <u>last</u> 10 years to 6 years	$1,360,000,000.

These figures show nearly a one billion dollar (1,000,000,000) dividend from a vigorous initial research and development attack even at the expense of much inefficiency and duplication. For a given overall reduction in total time, inefficiency at early stages, when total expenses are low, costs much less than later in a program which has an exponential growth curve.

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Figure 1 - B-32905
Figure 2 - A-38548-G
Figure 3 - A-38549-G
Figure 4 - A-38550-G
Figure 5 - A-38551-G
Figure 6 - D-32904

FIGURE 1

COMPARISON BETWEEN RADAR AND COMPUTER DEVELOPMENT

RADAR DATES	RADAR DEVELOPMENT (HISTORY) (Selected milestones to show progress)	CORRESPONDING ELECTRONIC COMPUTER STATUS (PREDICTED) (Selected milestones to show progress)	CORRESPONDING COMPUTER DATES
1925-35	DEMONSTRATION OF RADIO RANGE ECHO PRINCIPAL BUILDING OF EXPERIMENTAL SYSTEMS	BASIC ELECTRONIC CIRCUITS AND COMPONENTS ENIAC COMPUTER	1935-43
1936	CXAM AND SCR-268 EXPERIMENTAL MODELS	IBM COMPUTER	1947
1933-38	PRELIMINARY MAGNETRON RESEARCH	PRELIMINARY HIGH EFFICIENCY STORAGE RESEARCH (DELAY LINES AND STORAGE TUBES)	1943-48
1938-40	FIRST PRODUCTION RADAR (CXAM AND SCR-268)	MULTIPLE CONSTRUCTION FOR LAND-BASED EXPERIMENTAL USE	1953-55
	ACCELERATED WARTIME DEVELOPMENT PACE FOLLOWS FOR RADAR	CONTINUED PEACETIME PACE FOR COMPUTERS	
1941	EXPERIMENTAL MOBILE SCR-584 (FIRE CONTROL) EXPERIMENTS IN HIGH POWER FOR SM (SHIP BORNE FIGHTER DIRECTOR)	EXPERIMENTAL SEMI-MOBILE COMPUTER FOR CONTROL	1955
1942	FIELD TESTS OF SCR-584 — PRODUCTION CONTRACT EXPERIMENTAL LAND-BASED SM	FIELD TESTS IN MISSILE GUIDANCE EXPERIMENTAL SHIPBOARD FIRE CONTROL	1956
1943	FIRST PRODUCTION SCR-584 AND SM PROTOTYPE SM ON USS LEXINGTON	PROTOTYPE MISSILE AND FIRE CONTROL COMPUTER	1958
1944	FIRST COMBAT USE OF SCR-584 PRODUCTION OF REVISED SM (SP)	PRODUCTION SYSTEM FOR MISSILE LAUNCHING AND SINGLE-SHIP FIRE CONTROL	1961
1945	FIRST EXTENDED SYSTEMS DEMONSTRATION (PROJECT CADILLAC)	FIELD TESTING OF INTERCEPTION NETWORK, ANTI-SUBMARINE TASK GROUP CONTROL, AIR TRAFFIC CONTROL	1963

FIGURE 1.

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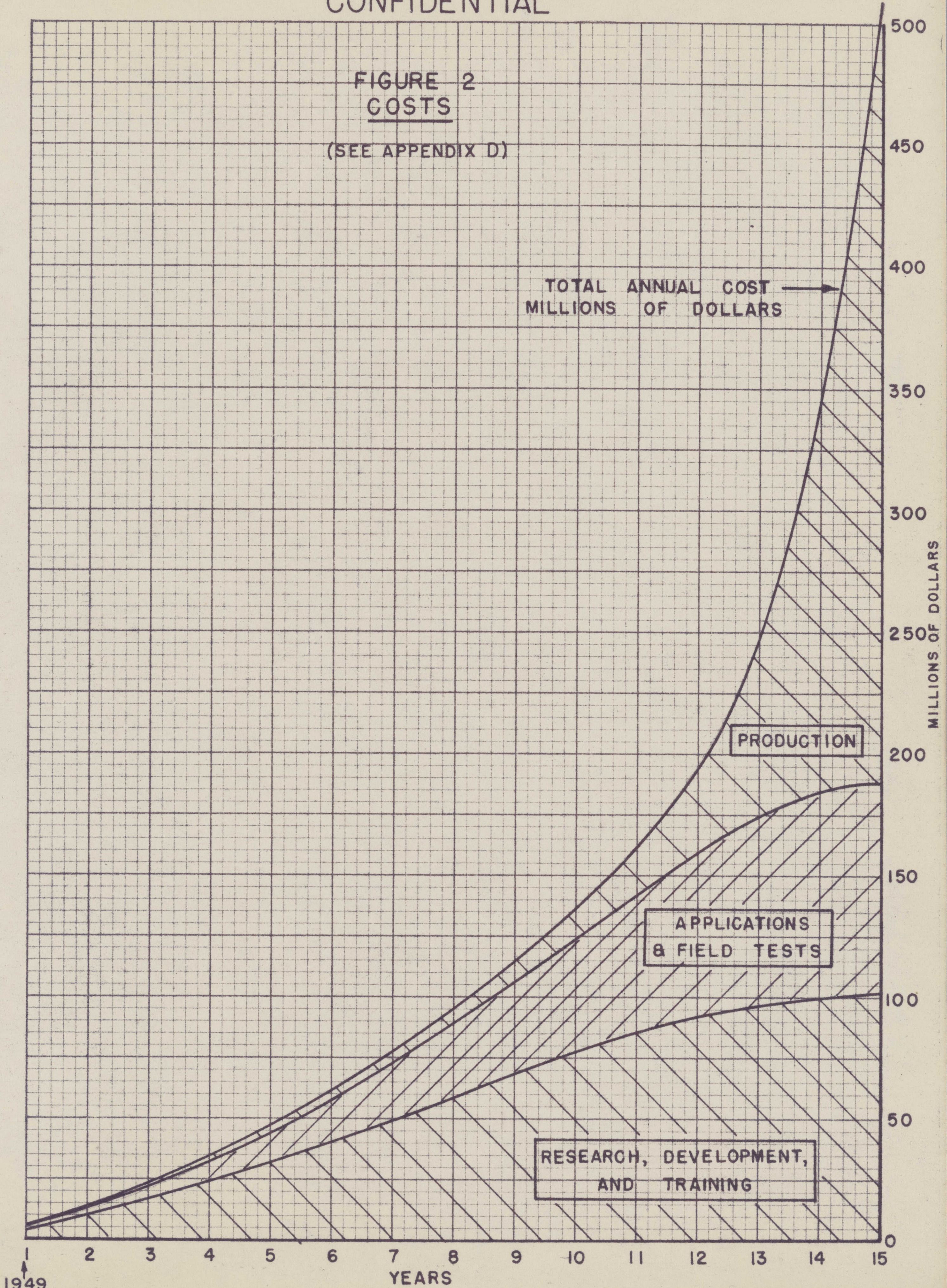
FIGURE 2
COSTS

(SEE APPENDIX D)



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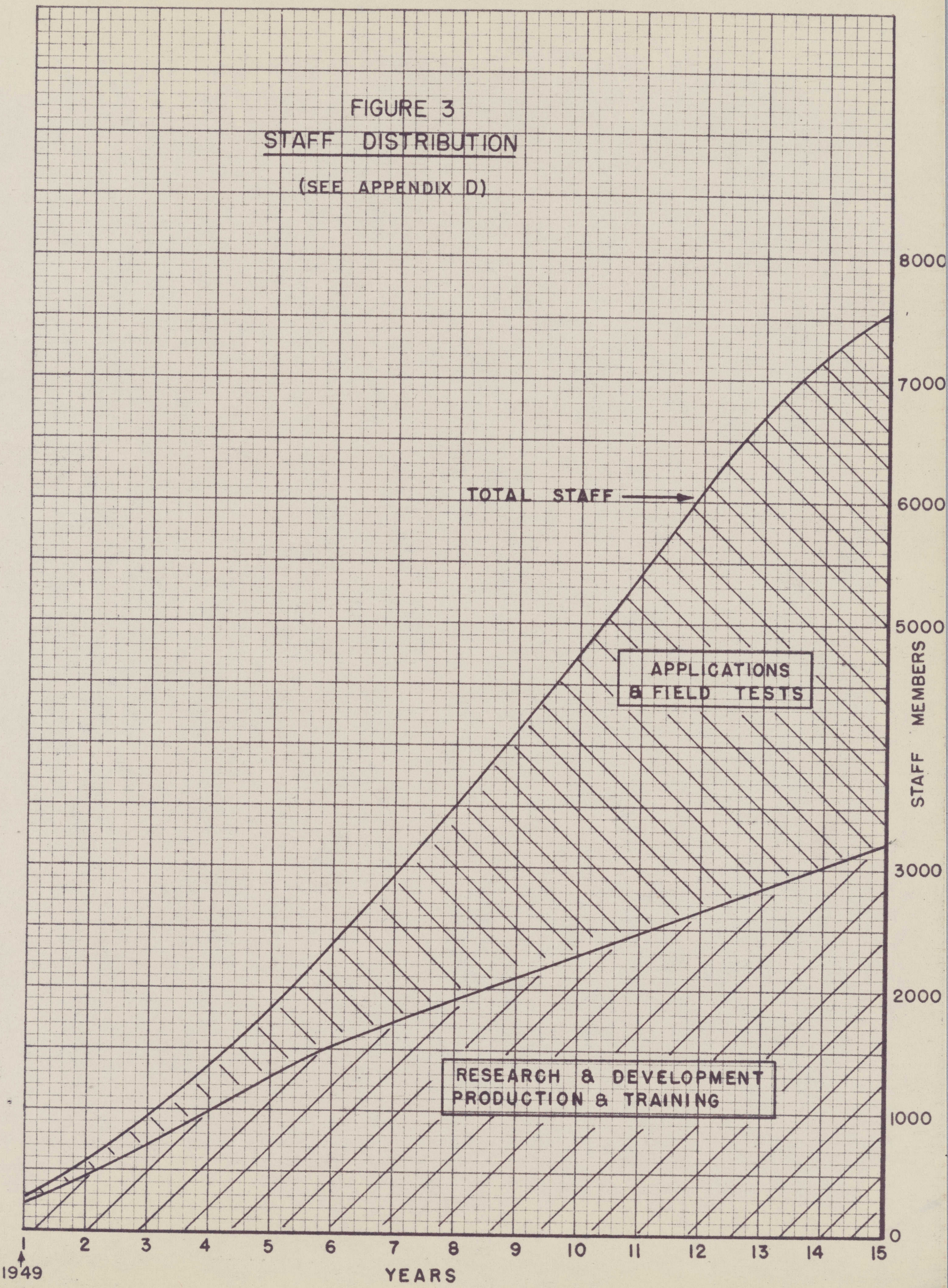

FIGURE 3
STAFF DISTRIBUTION
(SEE APPENDIX D)

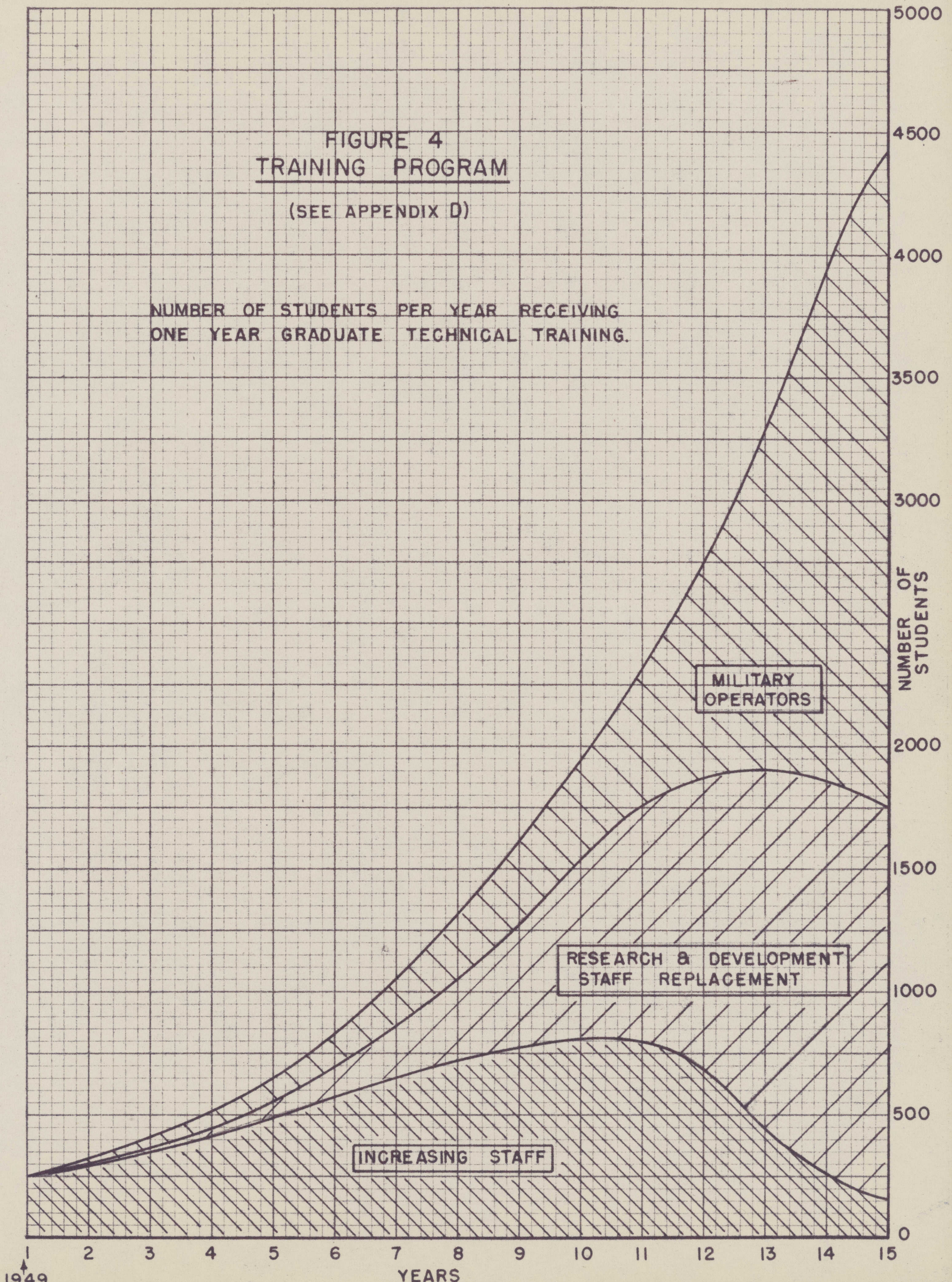

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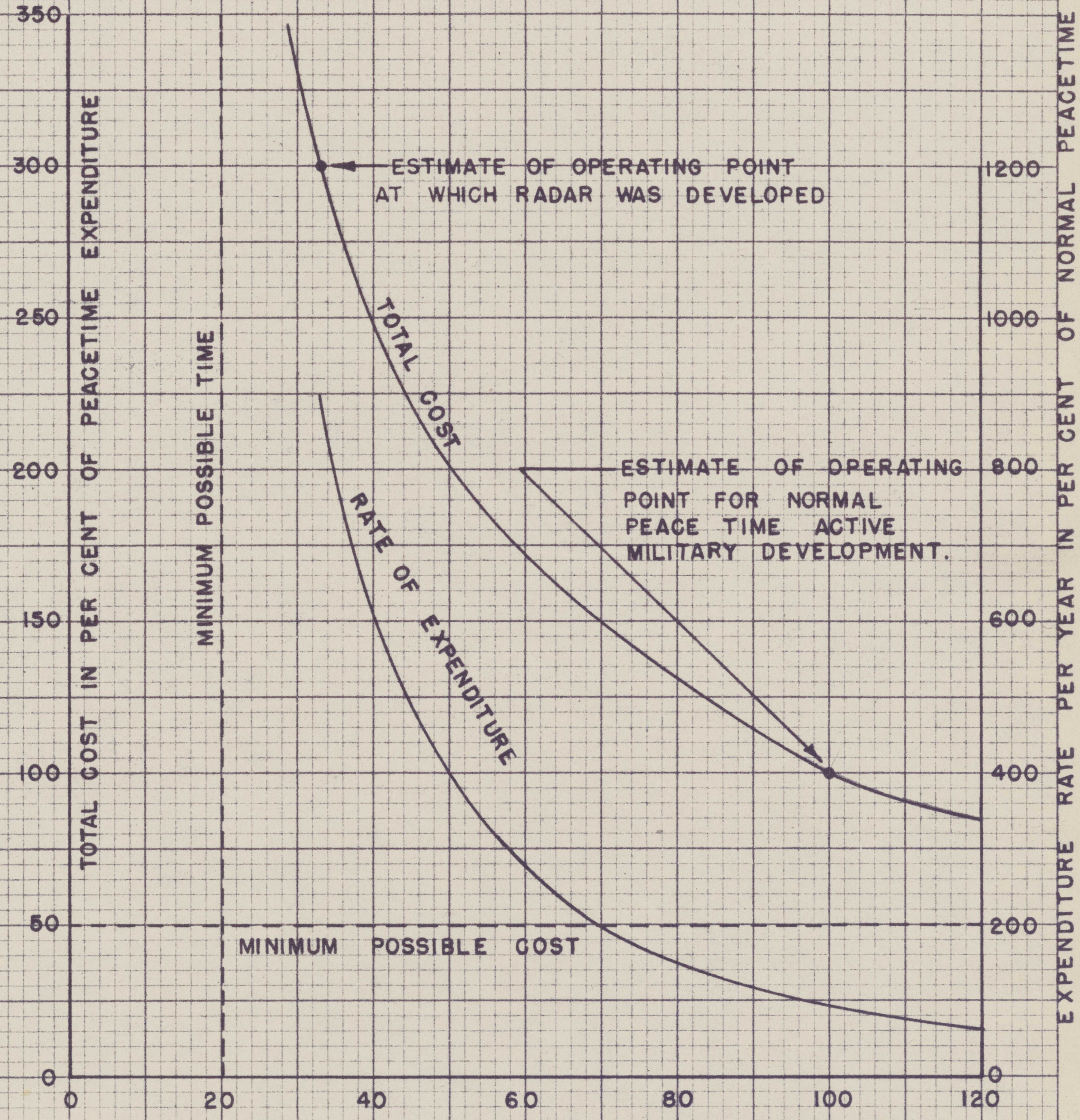
FIGURE 5

TOTAL COST vs ALLOWED TIME



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ACTIVITIES		1949	1950	1951	1952	1953	1954	1955	1956
BASIC RESEARCH	COMPONENT AND CIRCUIT DEVELOPMENT STORAGE SYSTEMS MATHEMATICS AND APPLICATIONS RESEARCH COMMON TO MANY USES	R1.9 CONTINUED INVESTIGATION	R3.7	R4.8	R8.3	R11.7	R15.4	R17.0	R17.6
TRAINING	RESEARCH PERSONNEL APPLICATIONS PLANNING OPERATING STAFF	R0.3 INFORMAL INSTRUCTION COURSES IN 1 OR 2 COLLEGES	R0.8 50 STUDENTS WITH MORE NEEDED IF FACILITIES WERE AVAILABLE	R1.4 250 STUDENTS	R2.2 500 STUDENTS	R2.8 650 STUDENTS	R4.4 850 STUDENTS	R4.9 1050 STUDENTS	R6.9 1300 STUDENTS
DATA CONVERSION	PHYSICAL MEASUREMENTS TO DIGITAL QUANTITIES DIGITAL TO PHYSICAL RADAR DATA TO DIGITAL FORM COMPUTER-TO-SERVO LINKS	R0.4 CONTINUED INVESTIGATION	R0.8	R1.8	R2.0	R2.2	R2.4	R2.4	R2.4
* ENGINEERING AND SCIENTIFIC COMPUTERS	GUIDED MISSILE DATA REDUCTION SURFACE SHIP AND AIRCRAFT STABILITY SCIENTIFIC COMPUTATION OPERATION EVALUATION ANALYSIS DESIGN COMPUTATION MATHEMATICS AND NUCLEAR RESEARCH CRYPTOGRAPHIC APPLICATIONS	R2.3 DESIGNS NOW IN PROGRESS	R5.0 FIRST EXPERIMENTAL HIGH-SPEED MACHINES	R6.0 LABORATORY TESTING AND STUDY	R7.0 E1.0 EXPERIMENTAL TRAFFIC NETWORKS	R8.2 E2.0 OPERATING TRAFFIC NETWORKS REDESIGNS	R8.8 P3.0 CONSTRUCTION OF ADDITIONAL COMPUTING FACILITIES	R9.5 P3.0 INSTALL ADDITIONAL FACILITIES	R11.9 P5.0 INSTALL AND OPERATE
FIXED LOCATION CONTROL SYSTEMS	INTERCEPTION NETWORKS AIR TRAFFIC CONTROL MANUFACTURING PROCESS CONTROL	R0.2 INTERVAL OF TIME FOR EVALUATION OF COMPUTER WORK, BUDGET PLANS, CONTRACT NEGOTIATION, SETTING UP LONG RANGE INTEGRATED RESEARCH AND DEVELOPMENT PROGRAMS. THIS TIME COULD BE REDUCED. IF SO, THE ABOVE ITEMS, PARTICULARLY TRAINING, MUST BE GREATLY INCREASED.	R0.4	R2.7 APPLICATIONS STUDIES PRELIMINARY DESIGNS	R3.2 BEGIN EXPERIMENTAL CONSTRUCTION DESIGN AUXILIARY EQUIPMENT	R4.4 E2.0 FINISH CONSTRUCTION OF FIRST EXPERIMENTAL INSTALLATION	R4.9 E3.0 INSTALLATION AND PRELIMINARY OPERATION FURTHER DESIGN	R5.9 E3.0 FIELD TESTS OF EXPERIMENTAL INSTALLATIONS	R6.8 E5.0 CONTINUED FIELD TESTS AND FURTHER EXPERIMENTAL INSTALLATION PROTOTYPE DESIGN
SIMULATION SYSTEMS	DESIGN STUDY SIMULATORS SYNTHETIC TRAINING WAR COLLEGE TACTICAL SIMULATOR GROUP TRAINING-AIR AND ANTI-SUBMARINE TEAMS		R0.1	R0.2 APPLICATIONS STUDIES	R0.5 CONTINUE STUDIES SPECIFICATIONS FOR EXPERIMENTAL USE	R0.8 E1.5 CONSTRUCT EQUIPMENT SIMILAR TO ENGINEERING COMPUTER DESIGNS	R1.3 E3.0 CONSTRUCT AND INSTALL DEMONSTRATION SYSTEMS	R3.6 P3.0 FIELD TESTS	R4.5 P3.0 EVALUATION OF TEST INSTALLATION
SEMI-MOBILE CONTROL COMPUTERS	SHIPBOARD COMBAT INFORMATION CENTER FIRE CONTROL RADAR DATA CORRELATION ANTI-SUBMARINE TRIANGULATION AND AUTOMATIC TASK GROUP ATTACK CONTROL		R0.2	R1.4 APPLICATIONS STUDIES PRELIMINARY DESIGN	R1.8 DESIGN EXPERIMENTAL SYSTEM	R2.2 E1.0 BEGIN CONSTRUCTION OF EXPERIMENTAL UNIT	R3.6 E3.0 FINISH CONSTRUCTION OF EXPERIMENTAL UNIT FOR SHIPBOARD	R4.2 E3.0 INSTALLATION ON SHIPBOARD	R4.8 E3.0 FIELD TESTS
MOBILE CONTROL (TRUCK AND LARGE AIRCRAFT)	MISSILE LAUNCHING CONTROL FOR ANTI-MISSILE DEFENSE AIRBORNE COMBAT INFORMATION CENTER		R0.2	R0.4 BASIC STUDIES INVESTIGATE SPECIAL COMPONENTS AND METHODS	R0.9 CONTINUED PRELIMINARY INVESTIGATION	R1.7 EXPERIMENTAL STUDIES	R2.8 E1.0 CONTINUE EXPERIMENTAL WORK DESIGN MODEL SYSTEM	R3.3 E2.0 CONSTRUCT EXPERIMENTAL SYSTEM	R3.9 R3.0 FIELD TESTS
AIRBORNE COMPUTERS	PRECISION MISSILE CONTROL AIRBORNE FIRE CONTROL		R0.1	R0.5 APPLICATIONS STUDIES STUDY OF SIMPLIFIED COMPUTERS	R1.0 EXPERIMENTAL RESEARCH	R2.0 BEGIN EXPERIMENTAL DESIGNS	R3.4 EXPERIMENTAL RESEARCH AND DESIGN	R4.2 CONSTRUCT EXPERIMENTAL EQUIPMENT	R4.4 E1.0 PRELIMINARY FIELD TESTS REDESIGN EXPERIMENTAL EQUIPMENT
LOGISTICS	SPECIAL INPUT-OUTPUT EQUIPMENT INTERCONNECTION WITH COMMUNICATIONS EQUIPMENT HIGH CAPACITY DATA STORAGE	R0.1	R0.2	R0.3 APPLICATION STUDIES	R0.6 TRIALS WITH EXISTING COMPUTERS	R1.7 EXTEND STUDIES BEGIN WORK ON TERMINAL EQUIPMENT	R3.6 DESIGN EXPERIMENTAL EQUIPMENT FOR LARGE-SCALE USE	R6.1 CONTINUED EXPERIMENTAL WORK CONSTRUCT SOME SPECIAL EQUIPMENT	R8.0 E2.0 BUILD MODEL INSTALLATION
COSTS (IN MILLIONS)	TOTAL YEARLY COST T	T5.2	T11.5	T19.5	T28.5	T44.2	T63.6	T75.1	T93.2
	TOTAL YEARLY RESEARCH R	R5.2	R11.5	R19.5	R27.5	R37.7	R50.6	R61.1	R71.2
	TOTAL YEARLY EXPERIMENTAL CONSTRUCTION E	0	0	0	E1.0	E6.5	E10.0	E8.0	E14.0
	TOTAL YEARLY PRODUCTION P	0	0	0	0	0	P3.0	P6.0	P8.0
	NUMBER OF STAFF REQUIRED	300	600	950	1350	1800	2400	2900	3500

ACTIVITIES	1957	1958	1959	1960	1961	1962	1963	STATUS AT END OF 15 YEAR PERIOD
BASIC RESEARCH	R17.6	R17.6	R18.6	R18.6	R19.8	R21.7	R23.0 CONTINUED INVESTIGATION	TOTAL COST T217.3 RESEARCH ON IMPROVED METHODS AND COMPONENTS SHOULD CONTINUE
TRAINING	R7.5 1600 STUDENTS	R8.5 1950 STUDENTS	R10.8 2300 STUDENTS	R11.4 2750 STUDENTS	R14.3 3250 STUDENTS	R15.1 3900 STUDENTS	R20.0 4400 STUDENTS	TOTAL COST T111.3 THE GREATEST PART OF THE TRAINING IS NOW IN OPERATING PERSONNEL
DATA CONVERSION	R2.4	R2.4	R2.4	R2.4	R2.4	R2.4	R2.4 CONTINUED INVESTIGATION	TOTAL COST T31.2 RESEARCH SHOULD CONTINUE
* ENGINEERING AND SCIENTIFIC COMPUTERS	R13.0 P5.0 INSTALL AND OPERATE	R15.6 P5.0 COMPUTERS NOW MEETING SCIENTIFIC AND ENGINEERING LOAD	R17.4 P3.0 COMPUTERS INCREASING IN USE	R18.2 P3.0 COMPUTERS INCREASING IN USE	R20.0 P4.0 COMPUTERS INCREASING IN USE	R21.0 P4.0 COMPUTERS INCREASING IN USE	R22.0 P4.0 COMPUTERS INCREASING IN USE	TOTAL COST T227.9 * R185.9 E 3.0 P 39.0 ALL LARGE SCALE ENGINEERING AND SCIENTIFIC CALCULATION NOW DONE BY COMPUTERS
FIXED LOCATION CONTROL SYSTEMS	R7.8 E6.0 PROTOTYPE CONSTRUCTION PRODUCTION DESIGN	R10.2 E10.0 PROTOTYPE FIELD TEST CONTINUED PRODUCTION DESIGN	R12.2 E10.0 P5.0 START PRODUCTION SYSTEMS	R15.6 E10.0 P10.0 PRODUCTION INSTALLATIONS TRIAL AIR TRAFFIC CONTROL SYSTEM	R21.0 E10.0 P20.0 PRODUCTION	R21.4 E10.0 P50.0 PRODUCTION	R21.4 E10.0 P100.0 PRODUCTION	TOTAL COST T402.1 R138.1 E 79.0 P185.0 PRODUCTION COMPUTERS AVAILABLE AND OPERATING IN CONTROL SYSTEMS. BULK OF PRODUCTION STILL TO COME
SIMULATION SYSTEMS	R5.1 P4.0 CONTRACTS FOR SIMULATOR CONSTRUCTION	R6.3 P6.0 UNITS BEING BUILT FOR TRAINING AND ENGINEERING SIMULATION	R8.3 P6.0 BUILD INSTALL AND OPERATE	R8.3 P6.0 BUILD INSTALL AND OPERATE	R11.4 P10.0 BUILD INSTALL AND OPERATE	R12.4 P10.0 BUILD INSTALL AND OPERATE	R12.4 P15.0 BUILD INSTALL AND OPERATE	TOTAL COST T144.0 R76.5 E 4.5 P63.0 HIGHLY FLEXIBLE TRAINING AND ENGINEERING SIMULATORS IN OPERATION
SEMI-MOBILE CONTROL COMPUTERS	R6.0 E3.0 FIELD TESTS PROTOTYPE DESIGN	R7.5 E6.0 PROTOTYPE CONSTRUCTION	R8.2 E6.0 PROTOTYPE FIELD TESTS PRODUCTION DESIGN	R8.8 E6.0 P8.0 START PRODUCTION	R10.6 E6.0 P15.0 FIELD TEST PRODUCTION UNIT	R10.0 E5.0 P50.0 PRODUCTION	R10.0 E5.0 P100.0 PRODUCTION	TOTAL COST T299.3 R79.3 E47.0 P173.0 OPERATING SHIPBOARD EQUIPMENT AVAILABLE. INSTALLATION COMPLETE ON SOME MAJOR FLEET UNITS. BULK OF PRODUCTION STILL TO COME.
MOBILE CONTROL (TRUCK AND LARGE AIRCRAFT)	R4.7 R3.0 FIELD TESTS PROTOTYPE DESIGN	R6.5 R5.0 CONTINUE EXPERIMENTAL WORK COMPLETE PROTOTYPE DESIGN	R7.8 R6.0 PROTOTYPE CONSTRUCTION PRODUCTION DESIGN	R9.6 E6.0 P2.0 PROTOTYPE FIELD TESTS. COMPLETE PRODUCTION DESIGN	R11.5 E5.0 P5.0 START PRODUCTION	R10.6 E5.0 P15.0 PRODUCTION	R10.6 E5.0 P50.0 PRODUCTION	TOTAL COST T188.5 R74.5 E42.0 P72.0 PRODUCTION MOBILE COMPUTERS BECOMING AVAILABLE. BULK OF PRODUCTION STILL TO COME.
AIRBORNE COMPUTERS	R5.2 E2.0 FIELD TEST	R6.8 E5.0 PROTOTYPE DESIGNS	R8.8 E6.0 PROTOTYPE CONSTRUCTION	R10.2 E6.0 P1.0 PROTOTYPE FIELD TESTS PRODUCTION DESIGN	R12.0 E6.0 P3.0 START PRODUCTION	R12.6 E6.0 P6.0 PRODUCTION	R13.0 E6.0 P15.0 PRODUCTION	TOTAL COST T147.2 R84.2 E38.0 P25.0 PRODUCTION AIRBORNE COMPUTERS AVAILABLE. BULK OF PRODUCTION STILL TO COME.
LOGISTICS	R10.4 E3.0 TRIAL TEST	R14.4 E6.0 CONSTRUCT PROTOTYPE EQUIPMENT	R17.9 E7.0 BEGIN WORKING INSTALLATIONS	R19.9 E6.0 P5.0 BEGIN EQUIPMENT PRODUCTION	R24.4 E 6.0 P10.0 PRODUCTION	R24.4 E 7.0 P20.0 PRODUCTION	R25.4 E 7.0 P35.0 PRODUCTION	TOTAL COST T271.4 R157.4 E44.0 P 70.0 COMPUTERS IN EVERY-DAY USE SOLVING LOGISTICS PROBLEMS. BULK OF PRODUCTION TO COME.
TOTAL YEARLY COST T	T105.7	T138.8	T161.4	T193.3	T248.4	T339.6	T512.2	GRAND TOTALS T2040.2
TOTAL YEARLY RESEARCH R	R 79.7	R 95.8	R112.4	R124.3	R147.4	R151.6	R160.2	R1155.7
TOTAL YEARLY EXPERIMENTAL CONSTRUCTION E	E17.0	E32.0	E35.0	E34.0	E34.0	E33.0	E33.0	E 257.5
TOTAL YEARLY PRODUCTION P	P9.0	P11.0	P14.0	P35.0	P67.0	P155.0	P319.0	P 627.0
NUMBER OF STAFF REQUIRED	4100	4700	5400	6100	6700	7200	7550	

NOTES: 1. ALL COST FIGURES ARE IN MILLIONS OF DOLLARS
2. STAFF WAS ASSIGNED TO SPECIFIC ACTIVITIES IN EACH YEAR. COSTS HAVE BEEN DERIVED AS DISCUSSED IN THE TEXT.

* 50% OF THE COST IN THE ENGINEERING AND SCIENTIFIC COMPUTER ROW IS FOR ROUTINE OPERATION. OTHER ROWS INCLUDE ONLY EXPERIMENTAL AND FIELD TEST OPERATION.

COST SYMBOLS
- T TOTAL
- R RESEARCH AND DEVELOPMENT, INCLUDING OPERATION AND FIELD TESTING, PRODUCTION DESIGN, AND SALARIES OF ASSIGNED TRAINEES
- E EXPERIMENTAL CONSTRUCTION COSTS
- P PRODUCTION COSTS (NOT INCLUDING DESIGN)

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FIGURE 6

FORECAST OF DIGITAL INFORMATION HANDLING PROGRAM

PROJECT WHIRLWIND SEPTEMBER 14, 1948
SERVOMECHANISMS LABORATORY D-32904
MASS. INST. OF TECHNOLOGY