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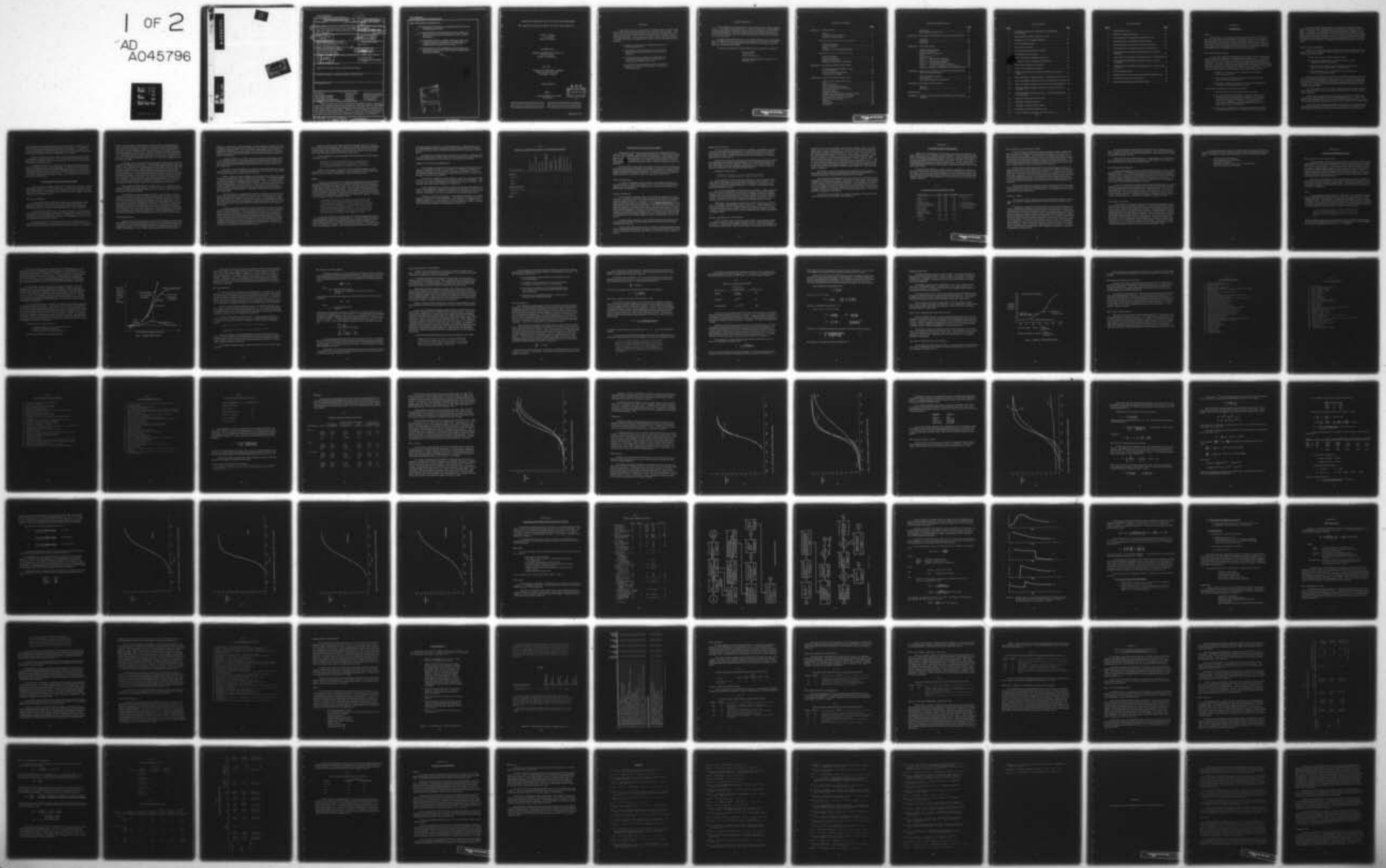

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Prior reports in this series defined four possible computer simulation models for predicting manning requirements on USN ships after the year 2000. This report selects the most promising of these alternatives and develops further detail relative to this model. However, since the model is based on several technical (relational) conjectures, as yet unproven, the major portion of the effort reported is devoted to the further investigation of the validity of

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these relationships and approaches:

- projection of manning level requirements based on the classical growth curve;
- decomposition of task complexity into five major constituent elements and determination of their relative importance;
- combination of these, together with known data, into a single analytical expression for extrapolation of manning levels decades into the future; and
- determination of the acceptability of this analytic expression in terms of the error based on Navy data for three ship functions.

PREDICTING MANNING LEVELS IN POST YEAR 2000 SHIPS

III. Manning Predictions Based on Growth and Complexity

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Arthur I. Siegel
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Allan R. Williams, Jr.

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CHAPTER I

INTRODUCTION

Purpose

Determination of a technique for predicting manning levels on future USN ships was the primary, long range goal of the present program. As one might expect, the ability to make such predictions is dependent on many diverse elements. The validity of such predictions is necessarily reduced as one projects years, even decades into the future and as the desire for generality in the process encompasses diverse ship types, ship missions, dynamic uncertainties in technology, and the as yet unknown tactics for engaging in future military sea operations.

Prior Work of This Program

In early 1975, Applied Psychological Services began its attack on this global problem with the full knowledge of the difficulty of the objective, i.e., a projection at least 25 years into the future. The first effort undertaken was directed at considering the practicality and potential of computer-based models for achieving such predictions. This effort resulted in the conceptualization of four alternate approaches. These were described in a year-end report (Siegel, Wolf, & Williams, 1975). A brief overview of these models is presented in Chapter II of the present report. The conclusions from this earlier nine month effort were generally positive in that:

- models such as those which were described incorporated the basic elements desired
- structures of the models were considered to be well within the state of the art for implementation
- combination of the elements of several of the models showed best promise for reasonable quantitative results

Nevertheless, the following risk areas were identified:

- availability of some essential input data was uncertain
- the proposed bases for extrapolation of manhour requirements into the next century was the classical growth curve operating on one variable called "automation level" and on another variable termed "complexity." However, the use of the growth curve represented an approach whose applicability had not been demonstrated for USN ship situations
- the key analytic expression in which the extrapolated automation level and complexity was to be entered had also not been verified

The next effort (of similar duration) served to consider further and refine the four alternative models, including a more comprehensive evaluation of their feasibility. Principally, the availability of required input data was evaluated in some detail. Secondarily, the mathematical functions describing the variables and the constructs in the models were evaluated. The results of the work were given in a status report (Applied Psychological Services, 1976). On the basis of these evaluations and formulations, an Extended Automation Level Model (EALM) was derived. It utilized concepts from several models. A summary of the EALM was presented in the 1976 report.

Content of Present Report

Chapter IV of the present report contains a current and extended view of the EALM. The EALM is designed to answer questions such as the following for a selected ship and mission type:

- How many men are required to man this ship?
- What is the possible effect of selected personnel-oriented tradeoffs on system performance?
- How will various social or human performance and man/machine interactive factors affect crew performance?
- What automation levels are predicted for selected time periods even beyond the year 2000?

Other work was completed in parallel with this model development. This segment of work towards the long term goals was directed to: (1) providing a more formal verification of the applicability of the growth curve to manpower extrapolations, (2) further study of the formulas for translating extrapolated automation levels into manpower hour estimates, and (3) demonstration that these formulas have validity in testable naval situations.

To set the stage for the first of these, Chapter III presents a brief overview of the traditional growth curve and its successful applications to population and biological situations.

Chapter IV also contains values of automation level for four ship functions projected from data averaged over several knowledgeable subjects. Lastly, these subject data on automation levels were fitted to a least squares, growth curve. From this, the best estimate constants for the growth curve are determined by ship function.

During the study of appropriate analytic expressions for converting the somewhat abstract automation level into man hours, the concept of the complexity of the tasks performed at each ship function was previously introduced. In the current work, it became clear that complexity should not be treated as a single entity, but rather should be decomposed into its several constitutent parts. To accomplish this, the techniques of multidimensional scaling were introduced. Chapter V describes the procedures, existing computer programs, and data collection approaches used to decompose and describe the "complexity" of Navy tasks.

Chapter VI shows the methods employed and the results achieved in making extrapolations using the growth curve. Here, actual data from as long ago as the early 1940s are employed, together with actual naval data from the current decade to predict future automation levels.

The appendix relative to the ship of the future discusses potential changes based on extrapolation from current technology. The balance of Chapter I contains two related expository sections to provide background information. The first describes technological forecasting methods, categorizes them, and summarizes the advantages and disadvantages of each category. The remaining section of this chapter discusses automation, its meaning, its goal, and its definition as used in this and in prior related studies.

Technological Forecasting Methods

There are several techniques which may be employed for forecasting, whether technological, economic, or other. The various techniques may, however, be generally categorized into three groups: intuitive methods, trend extrapolation methods, and the use of models. This section describes these techniques, together with the advantages and disadvantages of each.

Intuitive Techniques

Forecasting techniques which rely on judgments by individuals have been classed as "intuitive" by Ayres (1969) and by Cetron and Monahan (1968). This somewhat uncharitable term refers to the fact that judgments by individuals or groups can neither be controlled, made highly objective, or made repeatable.

Ayres (1969) held that forecasts by a single individual or a small group are commonly more accurate than are forecasts provided by larger groups, regardless of the eminence of the large group's members. Despite this, it seems that, in practice, projections made by larger groups of persons knowledgeable in relevant areas are likely to be more favorably received.

The negative aspects of group forecasts seem to be that forecasts made by groups whose members interact face-to-face are likely to be influenced by characteristics of the interpersonal relationships between group members. The group may follow a dominant member who becomes an unchosen leader in making its projections. Some individuals in the group may be reluctant to speak out with opinions they believe will be unpopular or unusual. Accordingly, the normal group discussion may not always be effective unless particular care is exercised in selecting and briefing members of such a panel. Ayres cited examples in which large panels have provided forecasts which were considerably in error in the conservative direction. He hypothesized that, among members of committees, the "unspoken rule" is generally to avoid being outflanked on the right, i. e., by the more conservative elements (Ayres, 1969).

A technique which controls the interfering effects of interpersonal relations is available for obtaining a group decision. This technique, called the Delphi procedure (Dalkey, 1967, 1969), generally involves soliciting individuals' opinions by mail rather than convening the group. Each participant is informed of the opinions of the overall group, as obtained by the mailing, together with reasons given by individuals for their opinions. Then, participating individuals are asked to reconsider and resubmit their opinions. They are again provided information on the group's decisions, and asked their opinions a third time, after exposure to details of other group members' reasoning on the topic at hand. The procedure is generally terminated after three iterations. This technique limits the interpersonal dynamics which may confound group forecasts and fosters independent consideration. However, it is not clear that the Delphi technique reduces the conservatism of group forecasts.

Some intuitive forecasts have been very accurate. Yet, in general, the accuracy of this approach is quite variable. However, intuitive forecasts cannot be assessed for validity without waiting to observe actual outcomes and then determining the accuracy of predictions made.

One advantage of intuitive forecasts is that they are obtainable at very low comparative cost and, except for the Delphi procedure, they are usually obtainable much more quickly than through the use of other approaches. However, it is likely that those providing the forecasts will be pleased to give the large numbers of forecasts required to allow consideration of effects of varying related events, varying aspects of the trend under consideration, and the like. As a result, we may expect the validity of such forecasts to degrade as the number of individual requests for quantitative assessments increases, or as the time for responding to such questionnaires increases. Also, due to the subjectivity of intuitive projections, the reliability of these projections should be considered low. Intuitive judgments may not reflect effects of changes in relevant conditions in a manner which is at all consistent.

Trend Extrapolation

Often a trend analyst will find that variables whose prediction is desired have been measured and monitored for some time in the past, thus making possible trend extrapolation as a mode of technological forecasting. According to Lenz (1968), the change as a function of time in measures related to technological advance tends to take an exponential form. Yet, in many cases, a limiting value may exist which physically or theoretically bounds the change. In these situations, an exponential rate of advance is also to be expected, but the absolute rate of advance lessens as the limit is approached asymptotically. The result is the S-shaped growth curve treated in Chapter III. Technological changes of many types may often be forecast, on the basis of known past events, under the assumption of exponential growth with or without the effect of a ceiling value.

A variable of interest may often be examined through its relationship with one or more related variables. Lenz (1968) showed that transport aircraft speed tends to be a fixed proportion of the speed of concurrent military aircraft, or equivalently, that transport aircraft speed equals that of military aircraft of a determinable number of years prior.

In the above case, both military and civilian aircraft speeds appear to be growing exponentially, so there is little gain in basing predictions of future transport speed on the expected advances in speed of military aircraft.

However, different related variables may yield different forecasts, even though the different variables may each be measured with confidence. Lenz (1968) presented a forecast of total annual transport aircraft miles as an example. Total plane miles in the mid-1960s appeared to be approaching an asymptote. Hence, one would assume little subsequent change in total plane miles. However, plane miles may be viewed as a function of passenger miles and aircraft size, assuming a constant load factor. Viewed in this way, total annual plane miles may be projected to drop substantially as total passenger miles approaches its asymptote while aircraft size continues to grow exponentially.

Projections based on extrapolation of observed trends may often be made very quickly and at relatively low expense. Such projections are highly objective, being solely dependent on the shape of previous trends. Since, in this approach, the past and future values of the variable of interest are described by a mathematical function, the validity of the forecast may be assessed by comparing observed values of the variable at selected points in time with values at the same times which are predicted by the function.

Probably the greatest weakness of trend extrapolation as a method of forecasting is its lack of capability to account for changes in the context of other variables in which a variable is embedded. Trend extrapolation forecasts must be based on the premise that the relevant context in which the variable operates has not only been isolated but that it remained consistent throughout the baseline period studied and will continue to remain constant through the period for which forecasts are desired. Dramatic effects, such as changes in resources and important technological breakthroughs in the baseline period or in the period for which projections are desired, will tend to invalidate values obtained through trend extrapolation. Moreover, consideration of such changes cannot readily be factored in.

If the user of the forecast cannot exercise any realistic control over the context in which a variable operates, then inability to assess the consequences of changes in context may not be a disadvantage. On the other hand, if the user can control the relevant context, then a forecast which cannot reflect the influence of his manipulations of the operating context is of extremely limited utility.

A further difficulty in trend extrapolation was summarized by Martino (Bright & Schoeman, 1973):

> Furthermore, since trend extrapolation is still largely an art rather than a science, there is no rigorously logical method for selecting the parameters to be extrapolated. It goes without saying that more research is needed in this field. (p.124)

Finally, in this regard, we note that trend extrapolation depends on a data base from which trends may be developed. The characteristics of the available data base will vary from field to field and from trend to trend within fields.

Models

A model or a simulation is more a method of handling forecasts of the intuitive and trend extrapolative type than it is an independent approach to forecasting itself. The benefit of forecasting through a model rests in the rigor with which assumptions or data are processed. In a model, trends, functions, and interactions are input as formal logical or mathematical statements. These statements are manipulated according to inflexible rules of logic in predetermined sequence, producing conclusions that are completely replicable, consistent with projections made by the model based on other inputs, and that reflect consistent levels of details and emphasis. As pointed out by Blackman (in Bright & Schoeman, 1973):

> ...Mathematical simulation of a system can only represent a real system to the extent that the equations describing the operation of the components of the system accurately describe the operations of the real system components. It is usually impossible to include equations for all of the myriad components of a real system because the simulation rapidly becomes too complex. It is, therefore, necessary to obtain an abstraction of the real system based on judgment and assumptions regarding which components of the real system are those which control overall system operation. (p.259)

Projections resulting from manipulation of numbers of equations may lead to valid conclusions which are not intuitively apparent. Forrestor (1961) has made extensive application of simulation techniques to forecasting the consequences of business managerial decisions. Predicted consequences of relatively modest adjustments by managers were said to be often of startling magnitude. This clearly demonstrates one advantage of models. They allow rigorous and consistent determination of results of possible variations in the operating context. Projections which are purely extrapolations of trends cannot deal with the consequences of such variations, and intuitive forecasts will not process the available data in a rigorously consistent fashion.

The validity of simulation models may usually be assessed at reasonable cost. The model may be used to predict known events in recent history, based on data describing preceding history and the accuracy of such predictions evaluated.

Comparison of Forecasting Approaches

The strengths and weaknesses of the three forecasting approaches discussed above are summarized in Table 1. In this table, a "+" indicates a strength, a "–" indicated a weakness, and a "0" indicates a relatively neutral rating. In Table 1, the indicated strengths and weaknesses are algebraically summed to provide an overall figure of merit for each technique.

The intuitive techniques are rated favorably, in general, in attributes related to utility, e. g., cost, responsiveness to varying questions, understandability. However, their low ratings on attributes such as objectivity, accuracy, reliability, and formality cause their overall ratings to be relatively low.

Trend extrapolations are indicated to possess the same overall rating as two of the intuitive approaches, although the strengths and weaknesses are differently distributed. Extrapolation is believed to be higher than the intuitive approaches on the objective considerations but lower on comprehensiveness and generality issues.

Models, as a forecasting technique, received favorable ratings in all columns of Table 1 except cost and understandability. Accordingly, this technique shows the highest composite score. The conclusion is drawn, therefore, in Chapter VII that the basic approach to a general solution of the problem should be models--if analytic tools for key model elements can be validated (see Chapter IV).

Table 1

Comparison of Alternative Approaches to Technological Forecasting

Types of Forecast	Objectivity	Accuracy	Cost of Development	Timeliness	Reliability	Additional Forecasts Available as Desired	Formality of Assumptions	Internal Logical Consistency	Responsiveness to Varying Questions	Understandability	Comprehensiveness	Composite
Intuitive												
Individual	-	-	+	+	-	+	-	0	+	+	+	2
Group	-	-	+	+	-	+	-	0	+	+	+	2
Delphi	-	-	+	+	-	0	-	-	+	+	+	0
Trend Extrapolation												
Extension or Trend	+	+	0	+	0	-	+	+	-	0	-	2
Correlation	+	+	0	+	0	-	+	+	-	0	-	2
Models	+	0	-	0	+	+	+	+	+	-	+	5

Automation and Its Measurement

"Automation" is one of the many new technical words that has entered the twentieth century language. Diebold (1952) indicated that he initiated its use, largely due to his concern over his inability to spell "automatization." He considered automation to refer to both automatic control of operations and automatic physical processes. (Diebold acknowledged that a Ford Motor Company executive, D. S. Harder, had independently begun to use the word to refer to "automatic handling of parts and material.")

Diebold pointed out that people tend to think more of control of processes and treatment of information as examples of automation, and tend not to include mechanization of physical processes in this category. He considered this conception overly limited and stated that automation should refer to product and process redesign and design of machinery, as well as to theory of communication and control.

Goals of Automation

Currently, considerable interest is evident in automation of systems and processes in both the civilian and military sectors. The objectives behind the automation trend may be placed in two categories: (1) economic, and (b) engineering (enhancement of capabilities).

Economic Incentives

The incentive for automation which is most frequently noted has to do with economics. In military and civilian contexts, manpower represents an increasingly large percentage of fixed cost. The labor content in product cost may be limited and often reduced by advances in automation. In its Monthly Labor Review, the U. S. Department of Labor (June, 1971) reported an overall trend in industry toward utilization of numerically controlled machine tools. This trend was said to be due to the significant reduction in production costs which is associated with adoption of numerically controlled equipment. Similarly, the Department of Labor pointed out that the economics of competition and rising wage, fuel, and material costs caused the railroads to implement technological change with the result that between 1957 and 1972, the railroads were able to reduce manpower involved in maintenance-of-way by 50 percent.

In terms of ship construction, Plato (1974) stated that the shipbuilding cost per bunk equals $15,000, and that the ship structure required per crew member weighs five or seven tons.

Finally, Rubis (1972) pointed out that, in addition to reducing operating costs, reduced manning through automation will help to relieve the shortage of military manpower. Automation may similarly raise efficiency of utilization of men, machines, and fuel.

Engineering Incentives

A variety of benefits to speed, accuracy, reliability, and capability of system operations are available through automation. Rubis (1972) stated that the reliability of operations increases with automation due to increased consistency of operation within standard limits. He also expected automation to increase safety by reducing opportunities for human error.

The Navy's new automatic message processing and distribution system (MPDS) has dramatically increased the speed and capacity of communication with ships and has achieved this with reduced manpower requirements. Gaites (1974) pointed out that, with regard to detection and fighting of shipboard fires, "no patrol system can equal the performance of the automatic sprinkler system."

According to Rubis (1972):

> The impetus to automate is in reality coming from the demand for ever more performance from our (weapon) systems. (p.66)

As an example, he cited the gas turbine ship drive. Gas turbines allow high power density, fast engine start-up, and almost immediate power response. The turbine plant which allows these benefits must be automated. Prevention of over-overspeed, maintenance of proper fuel flow, etc., cannot be accomplished through human monitoring and control.

Of course, disadvantages to automation may be identified. Military equipment must retain as much operability as possible while damaged or otherwise degraded. Automatic controls generally lack the versatility to operate under heavily degraded conditions when normal operating limits or normal methods or procedures must be ignored. Manual procedures must be available as backup to automation in order for operations to continue to the extent necessary after damage has been incurred.

Additionally, the consequences of offensive military actions can be most severe. Accordingly, although weapon aiming, arming, etc., is being automated, considerable reluctance exists to automate the actual command to fire. This is so despite the admonition that only a speed-of-light response may be adequate to counter an attack by a weapon, such as a laser, which is delivered at the speed of light (Siegel & Williams, 1976).

Measure and Definition of Automation

Given a constant amount of work to be performed by a man/machine system, its degree of automation may be gauged through the number of persons assigned to the system. A fully automated system requires no crew. A fully manual system requires a crew of some size. Thus, the level of future automation may be defined as a function of the ratio of the existing crew size to the crew size under a zero automation case. Consider a task which, under manual conditions, requires nine men. Assume that with limited automated aids, a crew of six can perform the task. Further, automation allows task performance by a crew of three. The ratios of crew size required under automation, to crew size required without automation, are 6/9 and 3/9, respectively. Subtracting from unity to cause larger values to reflect higher levels of automation, the two cases become 1 - 6/9 = .33 and 1 - 3/9 = .67. Or, as presented by Siegel, Wolf, and Williams (1976), automation level $P = 1 - \frac{n}{N}$, in which n represents manning level under the degree of automation in question and N represents manning level without automation. According to this equation, automation level varies between limits of 0 (fully manual system) and 1 (fully automatic system, unmanned).

The equation requires that transfer of responsibility for special tasks to other groups, such as transfer of food preparation tasks to supplying factories, be considered automation, since shipboard manning level is affected.

Use of this equation assumes that the amount of work to be performed by the man/machine system is held constant. If the amount of work changes, the necessary manpower level is affected independent of automation. For example, such a change in work load has occurred in Navy sonar operation. One operator and one supervisor were assigned to submarine sonar functions during the World War II era. Modern sonar systems are manned by a supervisor and three operators. This growth in manning is clearly due to management of increasingly capable sonars, not to retrogression of automation in this system.

To account for this situation, the concept of complexity of the task is introduced in later sections of this report (see Chapter IV).

CHAPTER II

ALTERNATE MODEL APPROACHES

Siegel, Wolf, and Williams (1975) included an overview of the approach, the logic, and content of four stochastic computer simulation models for predicting manpower requirements for ships of the post year 2000 era. The four models described are: (1) a technological extrapolative model, (2) a volumetric model, (3) a linear programming model, and (4) an automation level model. They are summarized here for background information and to show the origins of the currently envisaged extended automation level (EALM) model (Chapter IV) derived principally from the automation level model.

The phrase "ship function" is used to identify an integrated set of tasks performed on board ship for all of these models, as well as throughout this report. Table 2 shows 12 prominent ship functions together with the current and projected post year 2000 values of automation level as determined on the basis of interview derived ratings of nine subjects. The ratings are on a 0 to 4 scale and not on the scale discussed in Chapter I.

Table 2

Ship Functions and Their Automation Levels

Ship Function	1975	2000	Difference
1 Sonar	1.19	2.26	1.07
2 Fire Control	1.46	2.83	1.37
3 Radar	1.48	2.78	1.30
4 Communications	1.07	2.22	1.15
5 System Maintenance	0.50	2.08	1.58
6 Facilities Maintenance	0.52	1.43	0.91
7 Ship Control	1.25	2.50	1.25
8 Propulsion	1.33	2.76	1.43
9 Air Support	0.86	1.95	1.09
10 Administration	0.46	1.58	1.12
11 Command & Control Center	1.12	2.29	1.17
12 Messing	0.50	1.83	1.33
AVERAGE	0.978	2.209	1.231

Automation Level Code:

0 - fully manual
1 - slight automation
2 - moderate automation
3 - high automation
4 - fully automated

The Technological Extrapolative Model

In the technological extrapolative computer simulation model, emphasis was placed on numerical extrapolation of individual technological developments into the future (beyond the year 2000). The premise was that changes in technology will reflect not only on the equipments of future ships, but will also determine the missions of such ships including potential missions not now performed by ships at all. In describing this model, potential technological changes in the fields of electronics, signal processing, computational sciences, communications, materials, satellite support, energy utilization, lasers and displays were considered.

In order to predict the requirements of future ship systems, this model includes the calculation of interpolated values of technological capability for each technology area for the future time period to be simulated. A technology level is then determined for each ship function at that future time period, based on a table of dependency data. These data, provided as input, quantify the estimated relative importance of each technological area on each of 12 existing plus other defined ship functions. From this, the manning required is calculated and compared against the size of the crew to be simulated (specified as input) to determine how well the simulated crew performs.

Output is displayed for the future time period selected and includes crew performance projection, predicted technological levels, crew assignments, rates of personnel utilization, areas of over or undermanning, and a numerical value for overall man/machine system effectiveness.

Volumetric Model

The volumetric model emphasizes the projected allocation of space in future ships to estimate the manning requirements for ship systems well beyond the year 2000.

The space for equipment and personnel will vary as a function of future technology. Additionally, separation or combination of ship functions and assigned responsibilities will influence manning levels, space, and performance. To overcome the problems of conjecture and opinion involved in projecting as far into the future as post year 2000, this computer simulation model would simulate changes for a large number of hypothetical ship functions, each characterized by a number of parameters. The model would compute the volume available per crew member per function over a 30-50 year period. To implement this approach, typical curves representing variation in equipment volume over time are prestored for use singly or in combination during simulation. Some would reflect dramatic increases in volume as new equipment is introduced; others would show gradual increases or decreases, while still others reflect dramatic decreases due to technological breakthroughs or integration (consolidation) of ship functions.

The input parameters would include the time period to be simulated, a manpower "crowding" threshold, and printout detail options. Other input data would specify the urgency of ship functions, personnel required for various performance levels, and equipment volumes over time.

Output results would include equipment, manning assignment, unfeasible solutions, and feasible crew volumes by ship function. Data would be made available by time period to provide a history for each ship function.

Linear Programming Approach

Linear programming has become a standard mathematically oriented technique for maximization or minimization of some objective while satisfying constraining inequality conditions. For future ship simulation, the solution of the linear program is considered to be a potential subroutine embedded within one of the other models rather than a complete independent model of future ship manning estimation per se. It serves the purpose of optimum allocation of men to ship functions, from among the large number of potential feasible allocation schemes.

The crew is divided into a series of personnel types (specialties), and a matrix of data is input to the program indicating the percentage of the work which could be accomplished adequately by each type of man for each ship function. The "cost" of each type of personnel is also provided as input. Total cost serves as the function to be minimized. The principal output would be the number of men of each type to assign to each ship function. These data would then be available to the other models to allow the determination or measurement of adequacy of ship performance.

Automation Level Model

The automation level model is based on the concept of extrapolating numerical values for "levels of equipment automation" for individual ship functions into the future. It allows effectiveness values to be estimated by simulation for given future naval vessels, considered as man/machine systems. The implementation involves the determination of the total effort (man hours) required during a shift or watch of prespecified duration on the ship to be simulated. This is accomplished by extrapolating known 1975 automation levels for each of the 12 ship functions into the future. The Logistic (Pearl) Method is used for extrapolation. Given the workload, crew work speed, and crew qualification level parameters, an estimate is made of how well this given crew "performed" during a simulated shift. During each simulated computer run, men are assigned to ship function, and calculations based on predetermined program logic determine the ship system performance results.

This model lends itself to interactive operation by a ship systems analyst who operates a computer terminal, provides input data, makes run requests, and observes results. Such results would include the following for the future time period of interest:

- projected trends of automation
- crew performance by ship function
- ship system efficiency
- distribution of personnel time (over or undermanning)
- effects of personnel crosstraining

CHAPTER III

UTILITY OF THE GROWTH CURVE

Theory and Use of the Growth Curve

In the development of various elements leading to a predictive model for future manned ships, the concept of technological improvement arose early and was readily identified as a critical element. Many of the scientific disciplines which could influence crew or ship performance were outlined in Siegel, Wolf, and Williams (1975). The effect of such technology changes was seen to lead to the notion that automation levels in future ships could be expected to exhibit "continued growth." That is, increased automation of the various equipment and procedures which consitute the ship functions of current and future interest is expected to have a major effect on ship's manning and thereby ship's effectiveness.

Therefore, the treatment of the theoretical aspects of growth and growth dynamics was considered important in its own right as a basis for development of certain attributes of the anticipated predictive model. This chapter serves that need by presenting a discussion of the theoretical aspects of growth, together with some comments as to its application.

Scope

The development of growth theories evolved from a need to analyze and quantify the growth of plant and animal life--for, in fact, all living things grow. The biologist would assert that all growth, including that of populations, is fundamentally a biological matter. Even though our ultimate goal is an understanding of nonbiological growth, we find that the lion's share of research into growth has been accomplished by those whose interest is in plants and animals. Nor is this biological/mathematical growth research exclusively recent. Pearl (1925) reported that:

> ...the law according to which the growth of population takes place, a Belgian mathematician, P.F.Verhulst, had, as early as 1838 used this same (growth) curve which he called the "logistic curve" as the expression of the law of population growth.

We will see that the same basic characteristic formula and analyses which satisfactorily describe biological growth of an individual have also been successfully applied to the growth of aggregates of like entities, i. e., populations.

Growth of a population involves replication of its individual members. The population of number of organisms of a single species is normally measured by a count of its membership; its productivity is determined by the number of new individuals produced per unit time or by its mass or volume; its density is measured by the number of individuals per unit area or volume. Population growth is achieved by birth and immigration. The size of a population is decreased by death and emigration. Yet, in most theoretical considerations of population dynamics, immigration and emigration are ignored. Only birth and death rates are logically concentrated on.

Correspondingly, growth of an individual involves replication of cells and growth of cells, in turn, involves replication of molecules. Much is known about the mechanism of growth of biological organisms composed of cells, which take in material and build them into protoplasm, the living substance of which the cell itself is made. Thus, single cells grow from within (intussusception), yet can divide to form other cells. The repetitive process of expansion and division (i. e., reproduction) is central in the growth of living organisms, and proceeds as the cells are differentiated into specialized tissues (skin, muscle, etc.) under the control of regulator substances (hormones).

Thus, growth of population, individuals, and cells involve completely different physical and biological mechanisms. Nevertheless, the development of a general theory of growth, including equations to reflect the observed growth curve characteristics, has not traditionally proceeded from such an analysis. The shape of the "growth curve" is sufficiently simple and well defined that various investigators have found it useful to be studied in its general form as shown in Figure 1. In Figure 1, the size of the object or population being studied is shown as a function of time. Also identified are the principle elements of the phenomenon of growth. The x-axis represents time but scaling varies widely depending on the organism or population (from a few minutes for bacteria to centuries for the sequoia).

Three functions are shown in Figure 1:

1. potential growth in an unrestricted environment
2. growth in a limited environment
3. rate of growth in a limited environment

These will be discussed in subsequent sections.

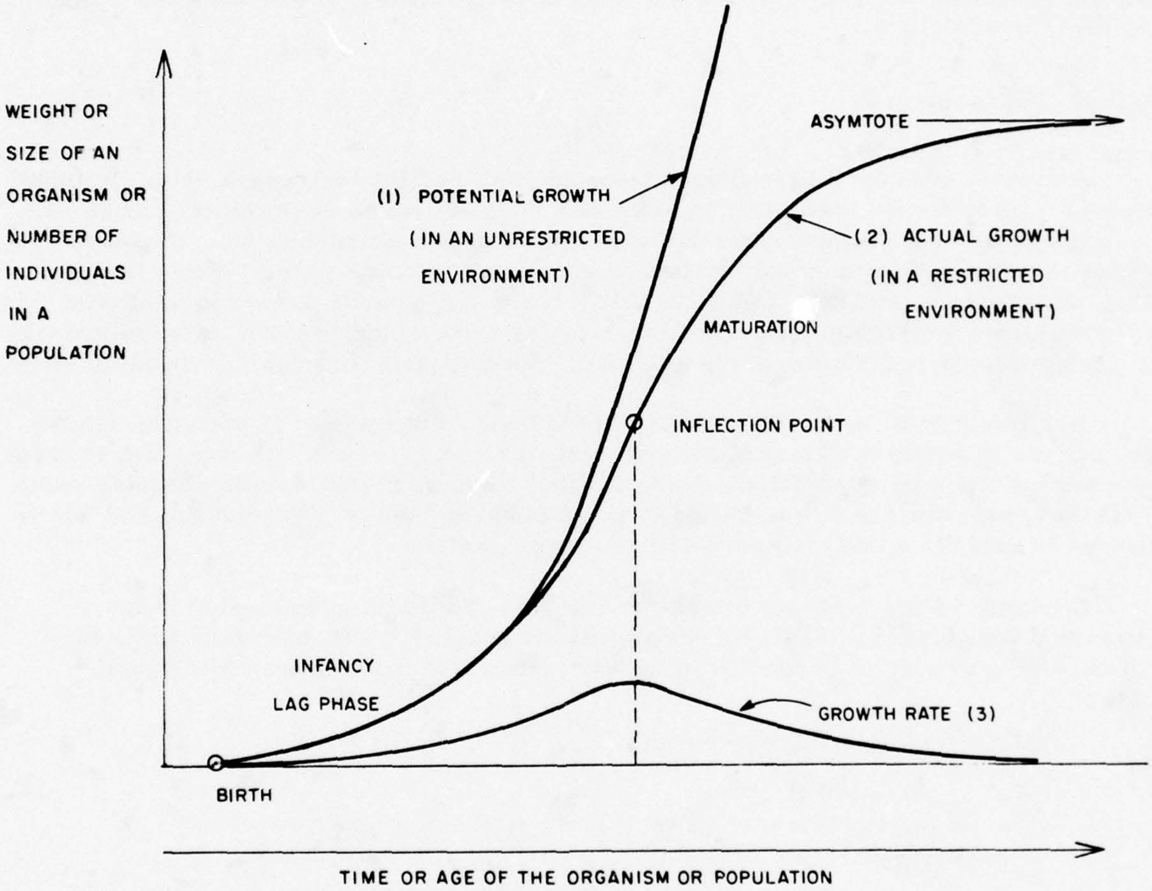


Figure 1. NOMINAL GROWTH CURVES.

The growth of living things has had considerably more attention that the growth of inanimate objects, and no general growth dynamics theory exists for inanimate objects. In the case of some inadequate objects, e. g., the formation of crystals, "growth" does occur but is limited. Crystals can increase in size but are unable to reproduce themselves. On the other hand, animate objects are not to be thought of as static. Even when mature, the adult plant or animal interacts with its environment most intimately. Thus, all animate growth must be considered as a transformation that occurs within a system consisting of the organism(s) and the environment by which it is sustained.

External Influences

A variety of external conditions can materially affect the growth rate. In most analyses, it is assumed that: (1) conditions are adequate so as to promote growth, and (2) conditions are not changed over the time period under consideration. The assumption that the total environment is limited is also made in some cases. For growth of plants, such factors as heat, light, humidity, soil, and gravity are important. In the general case for biological organisms, ranges exist which are conducive to growth, e. g., temperature, atmospheric composition, and available source(s) of sustenance.

For the case of technology growth in the Navy, the analogy of adequate conditions implies an absence of major national disasters, e. g., an intact economic/industrial complex and continued satisfactory political climate which devotes adequate basic and applied research resources to fields which could impact on ship design, and which continues to support a need for competitive (naval) power.

Linstone (1968) pressed the matter further. Supporting Quinn (1967) and Sherwin and Isenson (1966), in essence, Linstone concluded that the mere availability of excess technological capacity is insufficient in itself to cause technological growth:

> In fact, a technology is only utilized if it responds to a need.
>
> ...technological innovation was highly correlated with need-recognition.

Thus, any method or model which attempts to predict future ship manning which is so closely dependent on technological achievement of automation must make assumptions about the future need levels not only in resources available for technological research, but also about the naval needs generated by future wars of various types, political alliances, and the like.

All of these assumptions appear reasonable relative to the work of the present program.

The Unrestricted Environment

Assuming no changes in external influences, a population of size N(t) of time t in an unrestricted environment would grow indefinitely. Mathematically, one way to express this situation is by a growth rate at time t which is proportional to the size of the individual (or population) itself. This is represented by the differential operation:

$$\frac{dN(t)}{dt} = rN(t)$$

where:

$N(t)$ = population size at time t
r = intrinsic rate of population increase or size of the individual

The solution of this differential equation provides an expression for the size of the population:

$$N(t) = Ce^{rt}$$

where:

e = natural logarithm base
C = constant

Exceedingly rapid population explosion is anticipated with this exponential form, as shown by the "potential growth" curve in Figure 1. Every plant species is theoretically capable of overflowing earth resources if unrestricted growth continued, as defined by this equation. A simple numerical example is illustrative. If initial population $N(0) = 1$ when $t = 0$, and the growth rate is 10 percent per time period ($r = .1$), then $C = 1$ since $1 = Ce^0$ The anticipated population size for selected time periods is:

Time t	Size N(t)		
1	1.1	=	$e^{.1}$
10	2.7	=	e
100	2.2×10^4	=	e^{10}
1000	2.7×10^{43}	=	e^{100}

(In the mathematical analysis of this and subsequent equations, it is assumed that the population size N(t) is a continuous function of t with a continuous derivative at each instant. This assumption may not strictly hold for populations of individuals because changes are, in fact, quantum integer values. It is, nevertheless, a reasonable assumption in practice.)

Accordingly, the utility of the exponential growth function is limited to instructional value or to interest during the early growth period prior to the time when environmental limitations effects are noted.

Limited Environments/Technologies

Consider the more practical case of growth in a closed or limited environment. This is a realistic restriction since real growth is, in fact, limited and neither organisms nor populations exhibit unending growth.

In biological population growth (such as yeast growing in a limited nutrient medium, rats in a finite space, or fruit flies in a bottle), there is a ceiling on growth at the approach to the limiting condition. The simple effect of overcrowding limits the rate of growth. Licht (1967) indicated for example that "Numerous studies have shown that crowding in tadpoles results in inhibition of their growth rate."

Observation and experimentation have shown that crowding does in fact promote increased death rates and inhibit reproduction among various animal species. Sickness (promoted by greater proximity), malnutrition (due to limited food and water) and increased psychological stress may weaken individuals and interfere with mating in overcrowded situations. Severe overcrowding is considered a limiting and eventually an inhibiting factor in population growth. As these conditions are reached, population growth is said to encounter "environmental resistance."

Black and Edelman (1970) indicated that control over plant growth is exerted by chemicals (the phytohormones) through which limitations of the environment operate.

In the case of technological changes leading to growth of automation levels in ship functions, limitations can be considered from two points of view. First, there is the primary ceiling which is represented by the concept of complete automation. Certainly, technology cannot progress beyond the situation where there is complete absence for the need of any human intervention in a given ship function's tasks. This is the case in Table 2, represented by an automation level of 4. Here, complete automation, though a theoretical possibility for some ship functions, is a state which is seldom desirable in practice for most ship types. For example, the complete automation of the food function could be accomplished with today's technology by fully automatic vending machines, loaded only at port, together with disposable dishes and utensils. Ignoring practical acceptability for long missions, this approach is more akin to removal of the ship function from consideration than to full automation aboard ship.

The second technological limiting concept is that presented by Lenz (1968):

> Exponential growth tapers off when the technical area becomes so large that it competes seriously with other areas for funding or when the technical field becomes "mature"....when a technical field becomes specialized, standardized and overorganized, limits are placed on improvement in that field.

The discussion presented above seems to justify a conclusion that a limiting condition will be exhibited as a growth retardant to full automation in the Navy. Possible limiting conditions may be:

- the unacceptability of full automation to commanders as well as to ship designers
- the extensive technical difficulty or inherent impossibility of complete automation to the point of no manning
- the increase in cost per unit of increased automation compared to the cost of personnel as the full automation situation is approached
- the maturity of technological progress in certain areas resulting in lesser funding and attention

Carrying Capacity

The biological carrying capacity concept is introduced to clarify these limiting aspects. Carrying capacity is defined as the maximum steady state population of a given species which can be supported per unit area or volume. Since it is a steady state situation, the value can be exceeded in practice for short periods (e. g., in locust hordes which easily exceed the capacity of unit land to provide for a long term, supersaturated populations). Yet, the nominal limit set by some physical feature, such as food supply or space available, usually applies over the long term. The term "environmental resistance" has also been used to express this same concept that the resistance to further growth increases as the environment approaches saturation. This limit is represented by the asymptote in Figure 1.

Experience of many observers has shown that under some limitation, appropriate to the population being studied, the population curve follows the S-shaped (sigmoid) growth curve shown in Figure 1. This curve appears to be symmetrical about the point of inflection, the point at which the growth rate assumes its maximum value. As summarized by Black and Edelman (1970), this curve shows an initial small increase or lag phase, a faster or log phase, and then a plateau where growth has stopped. The part of the curve before the plateau is usually logarithmic to some extent but rarely follows (in practice) a perfect logarithmic curve because of the complexity of factors which influence and control the growth process. Generalization of this curve has resulted in equations of the form:

$$\frac{dN}{dt} = r \cdot N \cdot f(N)$$

in which the factor f(N) is selected for its limiting or damping effects so as to assume a value of zero when N is very large. This implies increasingly small growth as the population increases.

As a special case of limited growth, consider next the situation in which the population is assigned a maximum value M. This could represent some limit of food supply or physical space necessary to sustain M.

If we further assume that $f(N) = M-N$, the rate of growth is a function of the unfulfilled potential $M-N$, where N is the current size of the organism or population, We thereby mathematically induce M as an asymptotic maximum.

$$\frac{dN}{dt} = rN(M-N)$$

If r and M are constant, then a solution of this equation is of the form:

$$N = \frac{M}{1 - e^{-A(t-t_0)}}$$

where A is a constant and t_0 is the time at which $N = M/2$.

Pearl (1925) showed that the curve for the growth of a population of single cells is essentially the same in shape as that which was seen to describe the growth in size of a single individual multicellular organism. He also showed the applicability of this S-shaped curve to the human population of countries. He found that "all the complexities of human behavior, social organization, economic structure, and political activity do not seem to alter those same biological forces which determine the growth of human populations as well as yeast cells and fruit flies." He fitted size/population data to the generalized growth (logistic) curve which is similar in form to the one above:

$$Y = B + \frac{A}{C + e^{D_1+D_2x+D_3x^2+D_4x^3}}$$

by finding numerical values of the constants A, B, C, $D, \ldots, D_n$ for each population studied.

An even broader attribution of capability is bestowed on the sigmoid curve by Strassman (1976), and one more directly related to our interest in technology growth:

> "S" is the shape of growth. The "S" curve can be used to apply to the origin and growth of anything. It reflects the outcome of the underlining structural conflicts and balance from the conception to the maturity of any phenomenon. It can be found to represent histories of society (as expounded by Spengler to Toynbee), success patterns of organizations, market penetration patterns of products as well as life cycle of technologies.

Ayres (1969) and Ricklets (1967) summarized the work of Pearl and others in developing equations to reflect the sigmoid curve. In addition to the logistic equation, there are two other well known "growth" laws. The three are shown in Table 3.

Table 3

Comparison of Three Sigmoid Equations

Equation Type	Equation Form For Weight of a Growing Organism	Inflection Point
Logistic	$\frac{1}{1 + be^{-Kt}}$	1/2
Gompertz	$e^{-bK^{-Kt}}$	1/e
von Bertalanffy	$[1 - be^{-Kt}]^3$	8/27

In Table 3, K is a constant proportional to the growth rate and b is a constant such that the point of inflection occurs at t = 0 when b = 1 for the logistic and Gompertz equations and 1/3 for the von Bertalanffy equations. Although the equations appear very different in mathematical form, if the curves are superimposed with equal slopes at the point of inflection, they are difficult to distinguish. All yield the characteristic S-shape.

Ricklets (1967) calculated conversion factors for each of the three curves over the ranges of values taken at each one percent interval of the upper asymptote. He showed how these factors may be used in a simple procedure to facilitate the determination of the constants K and b for any of the three operations in Table 3 from experimental data. This graphic method solves the curve fitting problem at a level of approximation adequate for practical work on most measured data sets. During the process, the user is also able to determine the best of the three equations.

As an example, he showed that the weight (in grams) of the cactus wren is given by the equation of the logistic form

$$W = \frac{31.4}{1 + e^{-0.394(t-6.4)}}$$

where 31.4 is the asymptote determined graphically, -0.394 is a specified simple function of dWi/dt determined by graphing selected conversion factor constants, t is time in days, and 6.4 is the age of the wren at the point of inflection. The only input is the weight of the specimen wren(s) at daily intervals from 1 to 18 days.

Siegel, Wolf, and Williams (1975) discussed their investigation of these three alternative curves and found the logistic (Pearl) equation to be the most satisfactory for use in predicting level of automation. The scaling of the growth of the item being measured ranges asymptotically from 0 to 1 (not inclusive) as a function of time. Thus, the "no automation" and "complete automation" situations are never achieved.

They considered the automation level

$$P = \frac{1}{1 - Ae^{-Kt}}.$$

If at $t = 0$, $p = P_0 > 0$, then

$$P_0 = \frac{1}{1\ Ae^0} \qquad A = \left[\frac{1}{P_0} - 1\right] = \left[\frac{1 - P_0}{P_0}\right]$$

where P_0 = automation level at time $t = 0$.

If at $t = t_1 > t_0$, $P = P_1 > 0$, then

$$e^{-Kt} = \frac{(1-P)P_0}{P(1-P_0)} \qquad e^{-Kt_1} = \frac{(1-P_1)P_0}{P_1(1-P_0)}$$

$$e^{-Kt} = \left[e^{-Kt_1}\right]^{t/t_1} = \left[\frac{(1-P_1)P_0}{P_1(1-P_0)}\right]^{t/t_1}$$

Therefore, the following expresses the automation level P as a function of time t:

$$P = \frac{1}{\left[1 + \frac{1-P_0}{P_0}\right]\left[\frac{P_0(1-P_1)}{P_1(1-P_0)}\right]^{t/t_1}} \tag{1}$$

This equation is hereafter referred to as equation (1).

Changing Conditions

All of these findings on growth continue to apply so long as the principal conditions, including the limiting factors, remain constant. If a condition changes significantly (e. g., temperature, food, or space for plants and animals, or economic conditions for technology), a new growth curve which possesses different constants may become applicable.

Accordingly, a given S curve is applicable over an era or an age when conditions are not materially altered. Following some event, change of habit, war, or new cultural situation, a new growth cycle starts from a baseline of the already attained level at the end of the old epoch.

As a demonstration of this, Pearl (1925) graphed and derived equations for the population of Germany through its industrialization period (Figure 2). Note the shift in Figure 2 from one S curve to another during the period 1850-1875, and the fact that each curve possesses both a theoretical lower limit and an upper limit.

But the influence must be truly significant to divert the growth to another curve. As an example of the extent of insensitivity, Pearl showed that the native population of Algeria was unaffected by the introduction of the practice of contraception and improvements in public health.

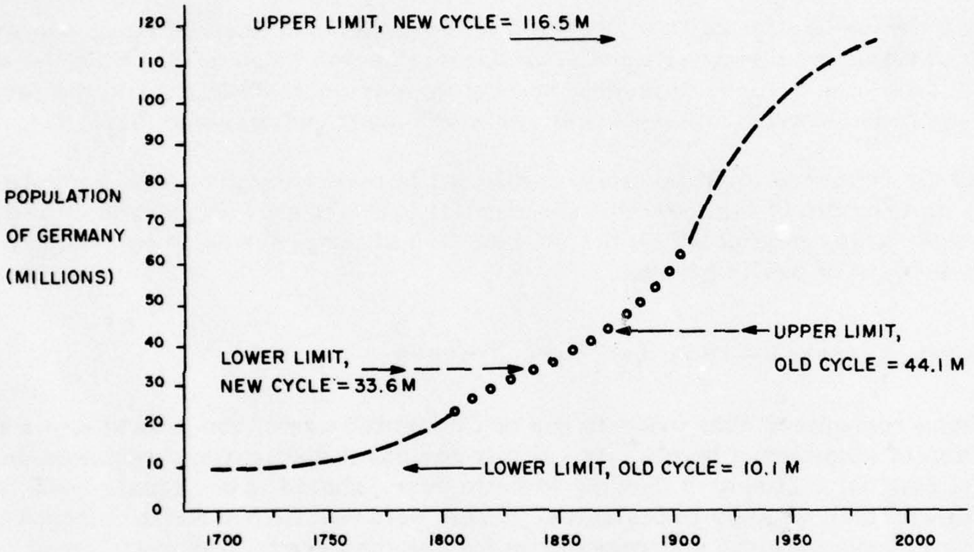
Growth Curve Extrapolations for Navy Systems

It was recognized that prior to the contemplated use of the growth curve for extrapolation of automation levels, its validity for naval applications required demonstration. Intuitively, it seems that the logistic curve should apply equally well to any situation in which an analogy to biological growth between a floor and a ceiling value is tenable. However logical and reasonable its use may seem, any model in which it appears would be enhanced considerably by such a demonstration.

The present approach to verification was to develop a growth curve for each of four ship functions on the basis of historical data. Then projections of each growth curve were compared with actual data. Next, a least square best fit curve was determined for each function. These best fit curves were used, in turn, to predict manpower requirements.

Selection of Ship Functions for Analysis

Of the 12 ship functions listed in Table 2, four were selected as representative since they are characterized by substantial ranges of automation level: messing, sonar, propulsion, and ship control.



OLD CYCLE (TO 1855) $y = 10.109 + \dfrac{34,036}{1 + 2.495e^{-0.0394x}}$

NEW CYCLE (FROM 1855) $y = 33.587 + \dfrac{82944}{1 + 297.546e^{-0.0472x}}$

Figure 2. EXAMPLE OF CHANGING CONDITIONS.

The automation of these ship functions as they exist on destroyers was selected for study due to the expected availability of data sources applicable to this large class of ships.

Automation Data Collection Procedure

Searches were made of potential civilian and military sources of published information through which automation levels might be determined. No usable information sources were found. Accordingly, historical automation data were obtained through estimation of automation of particular system functions by persons with expert knowledge of each selected ship function.

For each ship system studied, a list of man/machine functions was developed. These lists contained 25-30 items each. The function lists were developed on the basis of general knowledge of project personnel and examination of descriptions of relevant Navy ratings as found in NAVPERS 18068C (Bureau of Naval Personnel, 1971). Each function list was checked for comprehensiveness and freedom from redundancy by Navy officers with depth of operational experience aboard destroyers. The four function lists, as they appeared following the review by the Navy officers are presented in Tables 4 through 7.

Data Collection Procedures

Data describing the automation level of each listed item for each ship function were sought relative to three points in time. Navy experts were interviewed in order to obtain ratings, according to the scale shown in Table 8, for levels of automation of each listed item within each ship function for which the interviewee was knowledgable, together with the normal manning levels of these systems. The interviewees' knowledge was gained through operational, administrative, and R&D experience. Data were collected describing each system in the early 1950s, the early 1960s, and at the present times in ships representative of classes which were new at those times.

Table 4

List of Messing Functions

1. Preparing baked goods
2. Serving food and tending tables
3. Ordering food
4. Preserving and storing food
5. Cleaning eating utensils, food storage spaces, and cookware and equipment
6. Controlling quality of prepared food
7. Preparing menus
8. Inspecting eating utensils, equipment and personnel
9. Training mess system personnel
10. Maintaining inventory control of food stores and utensils
11. Preparing daily ration report
12. Making up daily and weekly records
13. Making up daily head counts
14. Preserving order on mess deck
15. Executing battle messing procedures
16. Monitoring the functioning of kitchen equipment
17. Maintaining watch quarter and station bill
18. Picking up and delivering mess laundry
19. Disposing of food and other related wastes
20. Cleaning deep fat fryers and equipment
21. Maintaining berthing space
22. Catering special events
23. Sequencing food preparation events to meet deadlines
24. Using safety procedures and precautions
25. Receive training
26. Prepare vegetables
27. Prepare meat and eggs
28. Prepare potatoes
29. Prepare salads
30. Replenishment
31. Prepare desserts
32. Stowage and breakout

Table 5

List of Sonar Functions

1. Select modes
2. Select visual display formats
3. Select integration times
4. Select hydrophone arrays
5. Select filters
6. Select frequencies
7. Select bands
8. Select beam width
9. Select D/E angles
10. Select active pulse parameters
11. Use noise suppression techniques
12. Record contact
13. "Tag" targets
14. Track target
15. Determine relative and/or true bearing of target
16. Determine target bearing drift
17. Determine target speed
18. Determine figure-of-merit
19. Detect torpedoes
20. Examine target signature on visual displays
21. Evaluate harmonics
22. Identify sounds of ships, marine life, and other phenomena
23. Operate stripchart recorder
24. Furnish sonar reports
25. Operate underwater telephone
26. Operate BT
27. Interpret BT data
28. Inspect and maintain equipment

Table 6

List of Propulsion Subsystem Functions

1. Taking on, transferring, and managing fuel
2. Testing fuel and water
3. Keeping logs and other record keeping
4. Executing casualty control procedures
5. Performing on board training
6. Using safety procedures on self, others, and equipment, etc.
7. Keeping up fuel service system
8. Maintaining propulsion cooling system
9. Detecting abnormal conditions at CCS
10. Performing functions in accordance with standard operating procedures
11. Performing with a knowledge of intersystem relationships
12. Implementing power distribution procedures
13. Exercising knowledge of system limitations
14. Maintaining distillation systems
15. Operating and maintaining auxiliary equipment, e.g., air compressors, steering stabilization gear, etc.
16. Demonstrating knowledge of equipment locations
17. Operating ECS (CCS)
18. Performing functions consistent with engineering watch structure
19. Coordinating between CCS and other stations
20. Performing functions consistent with PMS
21. Operating turbines
22. Maintaining turbines
23. Analyzing electrical, mechanical, and electromechanical problems
24. Performing preoperational checks and operating procedure at CCS
25. Monitoring system state at CCS
26. Operating at damage control/fuel control consoles
27. Operating and maintaining ship service gas turbine generator

Table 7

List of Ship Control Functions

1. Performing outstanding duties (include bridge preparation for getting underway)
2. Use magnetic compass and gyrocompass
3. Use timepieces and almanacs
4. Use, maintain, and stow navigational equipment (drawing instruments, fathometer, radar, sextant, stadimeter, star finder, sight reduction tables, charts, etc.)
5. Apply navigational data and perform necessary calculations
6. Use visual aids to navigation
7. Prepare and maintain required records and logs
8. Supervise and train personnel in navigational and watchstanding
9. Follow safety procedures
10. Collect meteorological data
11. Perform functions needed for anchoring and mooring
12. Collect navigational data (position, speed, etc.)
13. Determine position
14. Direct deck watch
15. Operate horns (foghorn and signal)
16. Detect ships and other hazards to navigation
17. Use maneuvering board
18. Determine and plot courses
19. Assure course/speed maintenance
20. Perform intership communications (radio, light, flags, etc.)
21. Perform intraship communication
22. Assure ship security and integrity
23. Coordinate ship functions
24. Integrate formation from internal and external sources
25. Make tactical decisions
26. Avoid obstacles
27. Recognition of special situations relative to ship and mission integrity
28. Derivation of appropriate courses of action relative to such special situations

Table 8

Scale of Automation Ratings For Interviews

Level of Automation	Automation Scale
Completely Automated	1.0
Highly Automated	0.8
Considerably Automated	0.6
Moderately Automated	0.4
Slightly Automated	0.2
Completely Manual	0

Mean automation levels were computed from the ratings provided for each time period. Automation levels for each ship function were then plotted as a function of time. Future estimates of automation were then calculated by plotting Pearl curves based on each available pair of data points and the assumption that growth was bounded by 0. 0 and 1. 0. These curves were generated through the use of the equation:

$$P = \frac{1}{1 + \left(\frac{1}{P_0} - 1\right)\left(\frac{P_0 (1 - P_1)}{P_1 (1 - P_0)}\right)^{\frac{t}{t_1}}}$$

in which P_0 is the automation level in the year t_0, and P_1 is the automation level in the year t_1.[*] Varying t allows determination of estimated automation level P at any year t, along with a growth curve passing through the points (P_0, t_0) and (P_1, t_1).

Details of procedures followed and results pertaining to the four systems examined are presented in the sections which follow.

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[*] This equation is identical to that presented earlier, except that the exponent in the denominator is adjusted to allow entry of calendar years instead of time difference in years.

Messing

Automation and manning data were obtained from a single individual who had extensive operational and managerial experience within the naval food delivery system. He provided automation data for the messing functions of a typical destroyer of the early 1950s, of the Sherman class destroyers as they existed in the early 1960s, and of the Spruance class destroyer of 1976. The three ratings obtained are presented in Table 9.

Table 9

Automation Levels, Estimated and Calculated

Ship Function	Year	Mean Rating From Subjects	Prediction Calculated From		Automation Level Differences	
			other 2 subject data points	least squares fit	(a)-(b)	(a)-(c)
		(a)	(b)	(c)	(d)	(e)
MESSING						
	1951(A)	0.038	0.054	0.038	0.016	0.0
	1962(B)	0.100	0.087	0.100	0.013	0.003
	1976(C)	0.219	0.301	0.219	0.082	0.0
	2000	NA	0.56-.81	0.68	--	--
SONAR						
	1952(A)	0.070	0.065	0.050	0.005	0.02
	1962(B)	0.195	0.202	0.179	0.007	0.016
	1976(C)	0.579	0.554	0.579	0.025	0.0
	2000	NA	0.95-.96	0.97	--	--
SHIP CONTROL						
	1945(A)	0.095	0.045	0.095	0.050	0.0
	1958(B)	0.158	0.230	0.158	0.072	0.0
	1976(C)	0.562	0.296	0.562	0.266	0.0
	2000	NA	0.56-.94	0.88	--	--
	1945(A)	0.100	0.034	0.100	0.066	0.0
	1958(B)	0.107	0.191	0.107	0.084	0.0
	1976(C)	0.400	0.117	0.400	0.283	0.0
	2000	NA	0.73-.87	0.72	--	--

Growth curves based on these data are presented in Figure 3. Each of the three curves is based on data points for two times: A and B (1951 and 1962), A and C (1951 and 1976), or B and C (1962 and 1976). Each curve passes through the two designated points and shows predicted values of automation well into the twenty-first century. For example, the curve based on automation levels at years A and B passes through . 039 in the year 1951 and through . 103 in the year 1962. At the point corresponding to the year 1976, the value of this curve is . 301, which differs from the mean rating given for 1976 by . 082 on the automation scale.

Of the automation levels at the three calendar years 1951, 1962, and 1976, each automation level is predicted by only that one growth curve which is drawn through the other two data points. The single prediction of each point and its absolute error relative to the mean of the corresponding automation ratings made by the interviewee are shown respectively in columns (b) and (d) of Table 9.

The predicted automation levels for messing in the year 2000 are . 807, . 642, and . 564 for the A-B, A-C, and B-C curves respectively. The data point B, representing automation level in 1962, appears too high, in the context of the other data points. This point appears to cause the variability in prediction. According to the interviewee, initial advances in automation of messing were controlled by equipment developments such as refrigerators, slicers, and potato peeling machines. More recent advances in the automation of the messing function have been due to advances related to food itself. Examples are provision of highly palatable, dehydrated foods, freeze-dried foods, convenience packaging, and factory prepared foods. It may be that automation in messing has entered a second growth cycle since 1962, and that, accordingly, the B-C curve most accurately predicts development in this field.

Sonar System

Interviews were conducted with three persons holding extensive experience in operation and development of surface ship sonar. All three persons, when interviewed individually, indicated that the sonar activities of interest were completely manual on all surface ships including the most recent. They stated that submarine sonars have been automated to a substantial degree, but funding had never been released which would allow surface sonar to advance in automation.

Accordingly, development of automation in submarine sonar systems was examined. An additional individual, possessing considerable experience in the development of submarine sonar, was interviewed. He was asked to rate the automation levels of each listed sonar activity relative to three submarine types. For early ratings, the interviewee rated the automation of the activities as they were performed using the BQR-2 and BQS-4 sonars, as in Guppy type submarines (1952). The intermediate ratings were based on the sonar of the Permit class (SSN 594) of 1962. These ships carried the BQQ-2 system which was composed of the BQS-6 (active), BQR-7 (passive) and BQS-8 and BQS-13 (active/passive) sonars. Ratings of automation of current sonar were made with regard to the BQQ-5 system.

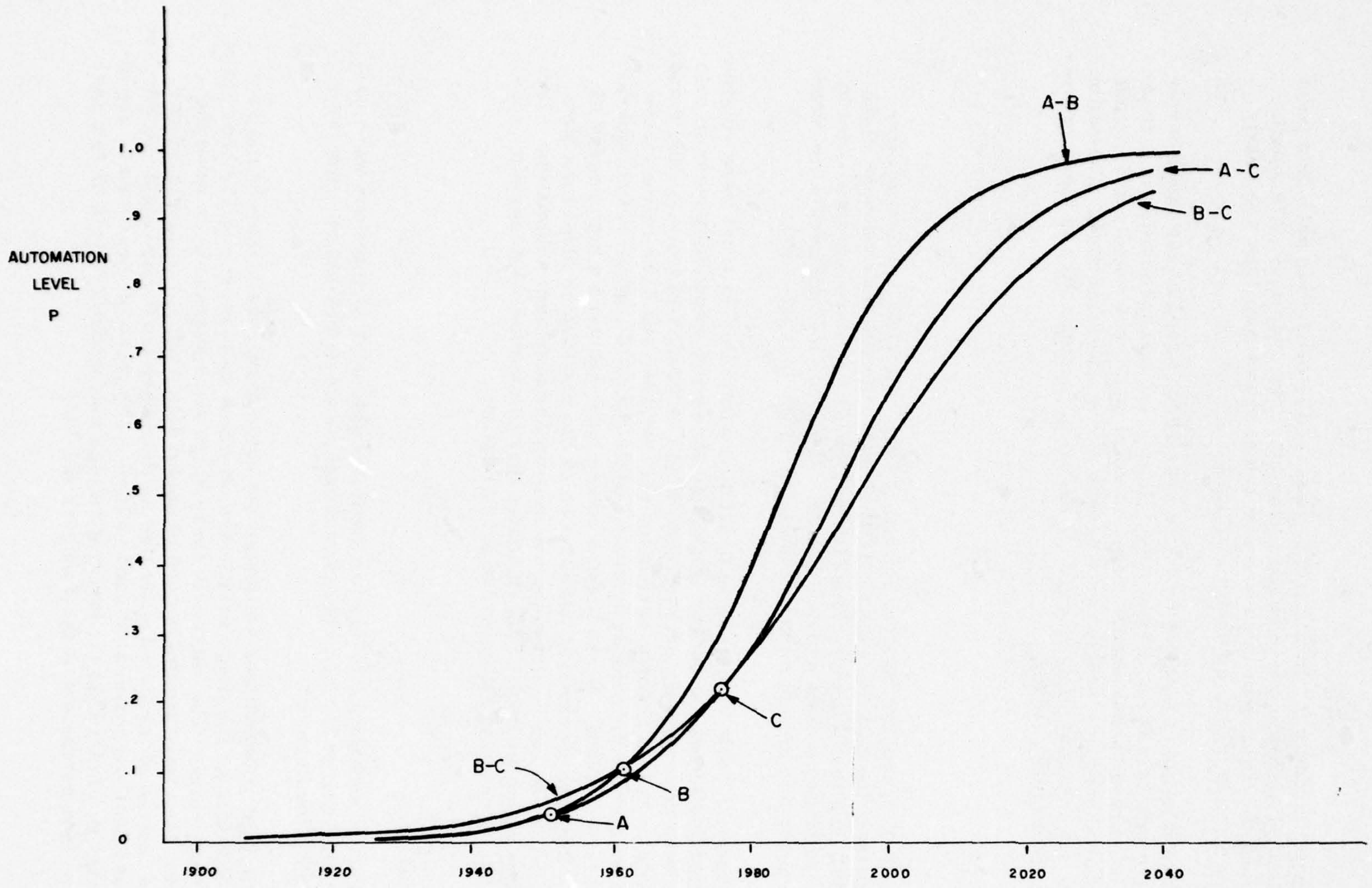


Figure 3. PROJECTED GROWTH IN AUTOMATION OF MESSING FUNCTIONS.

As shown in Table 9, the difference observed in predicting each data point from projection of a growth curve based on the other two points is quite small. Similarly, when the three growth curves are extended in time, they are nearly superimposed on each other, as shown in Figure 4.

Predicted levels of automation in the year 2000, based on the three developed curves, range only from . 954 to . 964. It appears that automation of submarine sonar, as viewed by one expert judge, is developing very rapidly and almost exactly as is predicted by a single cycle growth curve. Furthermore, automation of submarine sonar has already entered its period of formalization in the terminology of Nolan (Strassman, 1976).

Propulsion

Ratings of propulsion system activities were collected relative to three destroyer classes: the Gearing class [DD710] (1945), the Forrest Sherman class [DD931] (1958), and the Spruance class [DD963] (1976). Ratings were provided by three senior enlisted persons and one officer. The four interviewees were interviewed as a group and agreed on each function's rating that was made.

As shown in Table 9, errors in prediction within this data set were relatively large. Examination of the curves (Figure 5) shows that recent advances in automation have been considerably greater than would be predicted from earlier trends (the A-B curve). In this regard, it is noted that the 1945 and 1958 ratings were based on steam turbine propulsion systems, while the 1976 ratings reflect operation of a gas turbine plant. A gas turbine power plant requires a high degree of automation. It would appear that introduction of the gas turbine plant may have initiated a new, more rapid, growth cycle in propulsion system automation. The The high mean rating in 1976 (. 562) indicates that automation of propulsion systems may also be entering its period of formalization.

Ship Control

Ratings of automation levels for the listed ship control functions were provided by persons who possessed operational experience and by persons who were involved in ship development.

One bridge-rated officer estimated the automation levels representative of each of two World War II vintage destroyers on which he served: one Fletcher class and one Gearing class. The ratings of these ships were averaged, as were the years in which they were commissioned to obtain data point A. A single officer provided the ratings of the listed activities as they were performed aboard a Forrest Sherman class destroyer commissioned in 1958. The mean of these data is represented by point B. Point C is the mean of ratings independently made by two persons involved in development of the Spruance (DD963).

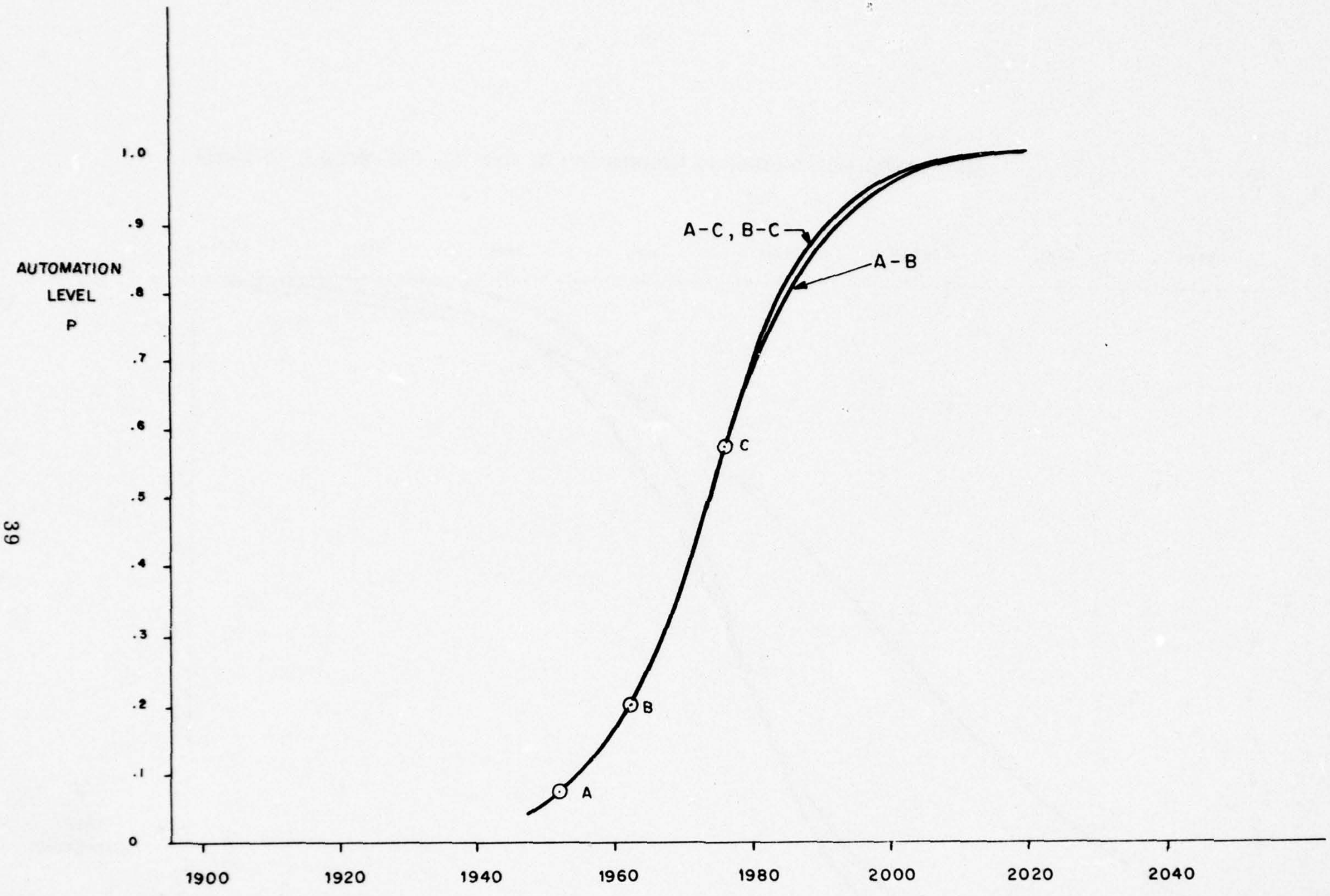


Figure 4. PROJECTED GROWTH IN AUTOMATION OF SONAR FUNCTIONS.

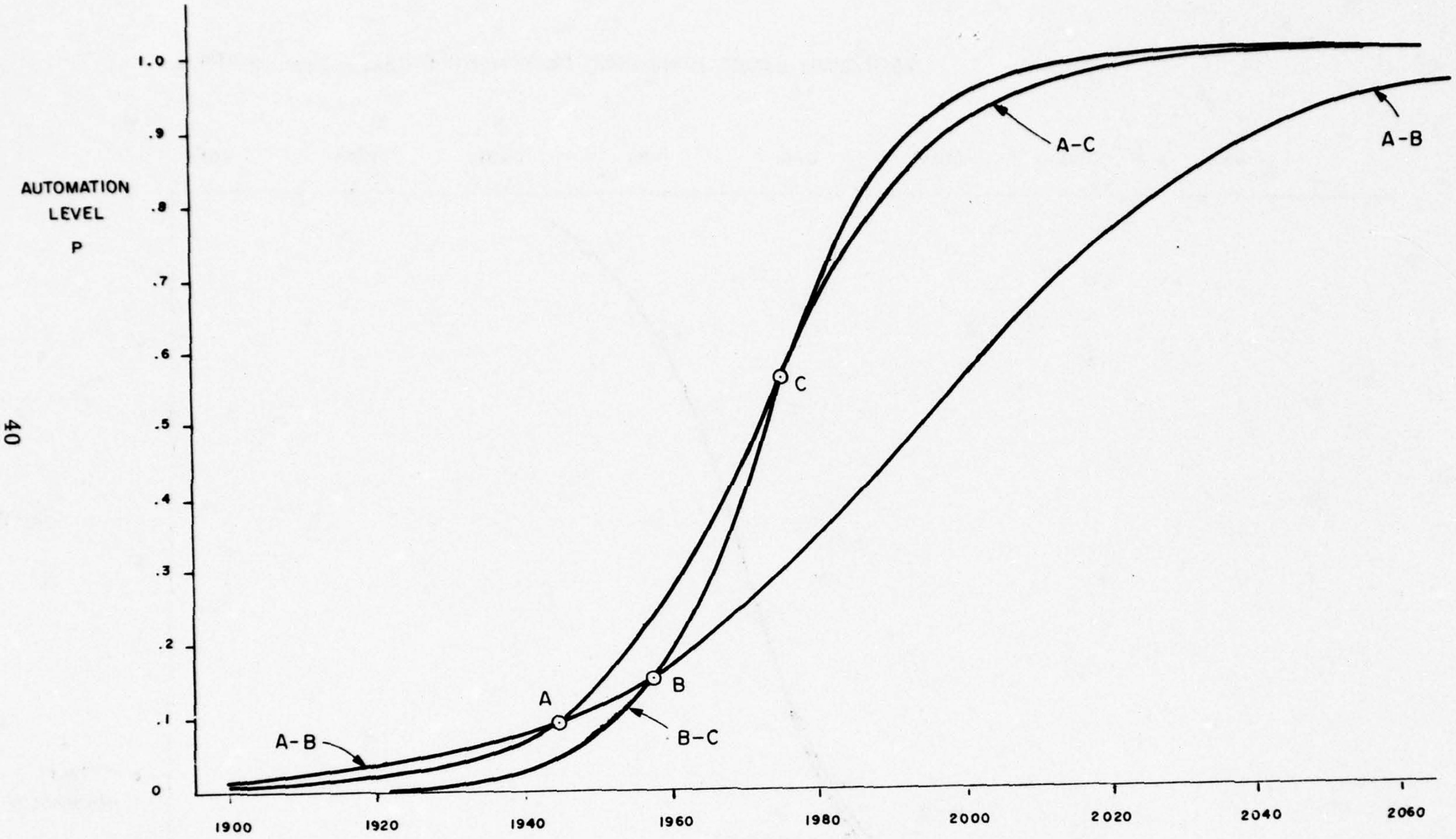


Figure 5. PROJECTED GROWTH IN AUTOMATION OF PROPULSION FUNCTIONS.

Examination of Table 9 and the associated Figure 6 indicates that essentially no growth occurred in ship control automation during the interval between data points A and B. A substantial change occurred, however, between 1958 and the present. A new growth cycle has apparently begun.

One overall by-product from Figures 3 through 6 is the impact one receives on realizing the high level of automation level growth now projected. From interviewee data alone, automation levels are expected to reach a 90 percent level at about the following periods:

Function	Year
Messing	2020
Sonar	1990-1995
Propulsion	2010-2020
Ship Control	2005-2020

We are left with the impression that, although men have been sailing in ships for thousands of years, and using them as fighting instruments for at least 500 years (??), with an almost completely nonautomated approach, it appears that during the relatively short span from about 1925 to 2025, almost complete automation is suggested.

Best Estimate Logistic Curve

In most cases, the sets of curves in Figures 3 through 6 indicated a range when alternate data points are selected as the basis for projection. Accordingly, a single, "best estimate" curve for each ship function was believed to be useful.

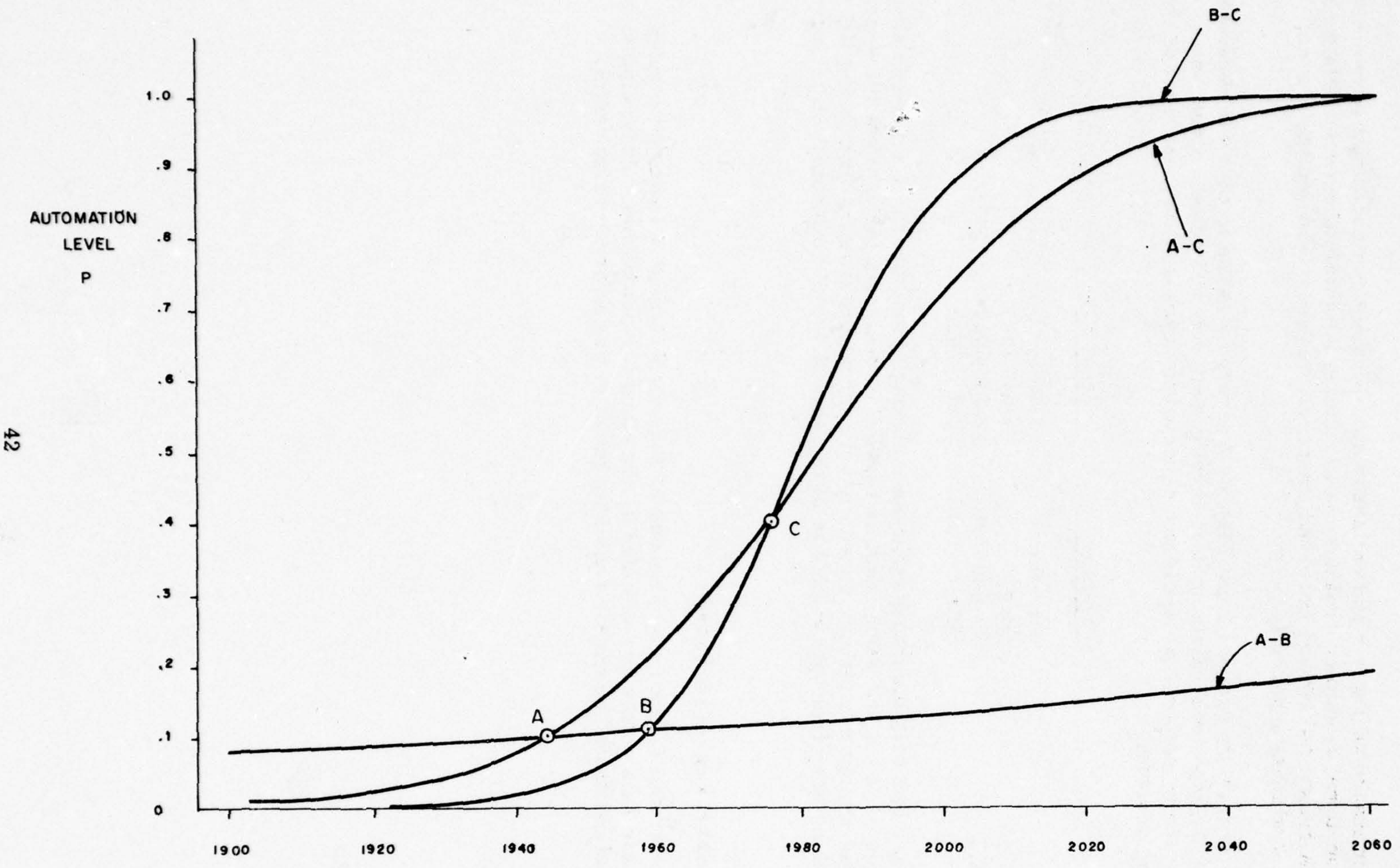


Figure 6. PROJECTED GROWTH IN AUTOMATION OF SHIP CONTROL FUNCTIONS.

This section presents the methods, procedures, and results relative to the development of best estimate logistic curves for the four ship functions. The data of Table 9 are employed. It is assumed that automation varies between none (AL = 0) and complete (AL = 1).

A logistic curve is defined by a function of the form:

$$P = \frac{1}{1 + A\exp^{(-kt)}}$$

passing through two given points $(0, P_0)$, $(t\ , P_1)$. We have shown above that this can be expressed as

$$P = \frac{1}{1 + \frac{1}{P_0} - 1 \quad \frac{P_0(1-P_1)}{P_1(1-P_0)} \quad \frac{t}{t_1}}$$

. Alternatively, A and h can be calculated:

$$A = \frac{1}{P_0} - 1, \quad k = \frac{1}{t_1} \ln \frac{P_1}{P_0} \cdot \frac{1 - P_0}{1 - P_1}$$

and used in the original natural base formula.

If more than two data points are to be used, the procedure becomes more difficult. The objective is to calculate A and k based on the three data points for each ship function, Table 9, by a least squares fit. Pearl presented a method which, in our case, yields two simultaneous equations. To implement the method, the general equation is first expressed as:

$$P = \frac{\frac{1}{A}}{\frac{1}{A} + e^{-kt}} = \frac{a}{a + e^{-kt}}, \quad \text{where } a = \frac{1}{A}$$

Let k = K + h, where K is an initial approximate value resulting from fitting the curve through two convenient, given points, and h is a small correction to be determined by the least squares procedure. Then:

$$P = \frac{a}{a + e^{-(K+h)t}} = \frac{a}{a + e^{-Kt}\,e^{-ht}} .$$

For small h, e^{-ht} can be approximated by the first two terms of the Maclaurin series: $e^{-ht} \approx 1-ht$, giving a linear approximation for $|ht| << 1$ or $|t| << |\frac{1}{h}|$.

$$P = \frac{a}{a + e^{-Kt}(1-ht)}$$

Once determined, any point lying on the curve satisfies the equation. Such a curve is determined so as to "best fit" the points in the least squares sense. Multiplying the left side by the denominator of the right side and transposing the a gives:

$$Pa + Pe^{-Kt} - Pth^{-Kt}h - a = 0$$

$$(P - 1)a - Pte^{-Kt}h + Pe^{-Kt} = 0$$

Call the left side r (residual). For a point on the curve, $r = 0$. The closer a point is to the curve, the smaller r is.

We wish to determine a and h such that Σr^2 is a minimum where the summation is over all points, (t, P).

$$\Sigma r^2 = \Sigma\left[(P-1)a - Pte^{-Kt}h + Pe^{-Kt}\right]^2$$

For a minimum $\frac{\partial\Sigma r^2}{\partial a} = 0$ and $\frac{\partial\Sigma r^2}{\partial h} = 0$, giving two simultaneous equations in a and h.

$$\frac{\partial\Sigma r^2}{\partial a} = 2\Sigma\left[(P-1)a - Pte^{-Kt}h + Pe^{-Kt}\ (P-1)\right] \equiv 0$$

$$\frac{\partial\Sigma r^2}{\partial h} = 2\Sigma\left[(P-1)a - Pte^{-Kt}h + Pe^{-Kt}\ (-Pte^{-Kt})\right] \equiv 0$$

This yields:

$$a\Sigma(P-1)^2 - H\Sigma tP(P-1)e^{-Kt} = -\Sigma P(P-1)e^{-Kt}$$

$$-a\Sigma tP(P-1)e^{-Kt} + h\Sigma t\ P\ e^{-2Kt} = \Sigma tP-e^{-2Kt}$$

These two simultaneous equations, when solved, give a new value of a and a value of h for calculating a better value of K.

As an example, consider the messing automation data:

Year	t	P
1951	0	.038
1962	11	.100
1976	25	.219

Using the first and third points for the initial curve gives:

$$A = \frac{1}{P_0} - 1 = \frac{1}{.038} - 1 = 25.316 \text{ and}$$

$$k = \frac{1}{t_1} \ln \frac{P}{P_0} \cdot \frac{1 - P_0}{1 - P_1} = \frac{1}{25} \ln \frac{.219}{.038} \cdot \frac{1 - .038}{1 - .219} = .07840$$

$$P = \frac{1}{1 + 25.316e^{-.0784(y-1951)}} \quad \text{where y is the zero.}$$

Actually, only the value of k is needed. The calculation is shown in tabular form below:

Year	t	P	$(P - 1)^2$	$P(P - 1)e^{-Kt}$	$tP(P - 1)^{2\,-Kt}$	$tP^2 e^{-2Kt}$	$t_2 P_2 e^{-2Kt}$
1951	0	.038	.9254	-.0365	0	0	0
1962	11	.100	.8100	-.0380	-.3180	.0196	.2156
1976	25	.219	.6100	-.0241	-.6025	.0238	.5950
		Σ =	2.3454	-.0986	-1.0205	.0434	.8103

The "normal" equations are:

$$2.3454a + 1.0205h = 0.0926$$

$$1.0205a + 0.8103h = 0.0434$$

Solving simultaneously gives:

$a = 0.41448$ $\qquad$ $h = .001361$

$A = \frac{1}{a} = 24.13$ $\qquad$ $k = K + h = .07840 + .00136 = .07976$

The least squares equation is:

$$P = \frac{1}{1 + 24.13e^{-.07876\,(y-1951)}} \quad \text{for messing.}$$

Note the small changes produced in A (4.7%) and in K (1.7%). For an $h = .001361$ and $t = 50$ years, $1 - ht = 1 - .068$ is a good approximation for $e^{-ht} = e^{-.067} = .934$. For $|t|$ smaller than 50 it is even better. Therefore, the least squares fit is quite accurate. If there is any doubt, the latest value of K can be used and the process repeated. In that case, the changes in A and in h would be found to be negligible.

The formulas for the other shipboard systems are:

$$P = \frac{1}{1 + 18.75e^{-.1377(y = 1952)}} \qquad \text{for sonar}$$

$$P = \frac{1}{1 + 11.08e^{-.0785(y = 1945)}} \qquad \text{for propulsion}$$

$$P = \frac{1}{1 + 11.58e^{-.0606(y = 1945)}} \qquad \text{for ship control}$$

Graphs of automation level for the various activities are shown in Figures 7 through 10, and the least squares points are tabulated in Table 9.

Automation levels in the year 2000 may now be projected by inspection of Figures 7 through 10, or by calculation. On the automation level scale ranging from 0 to 1.0, in the year 2000 the automation level of sonar is projected to be 0.97; messing, 0.68; ship control, 0.72: and propulsion, 0.88. (Of course, these projections are valid only in constant environments. If the level of funding available, for example, changes significantly from levels available during the 1945-1975 period, then the logistic curves describing the affected area will be modified.)

Stated alternatively, a 90 percent level of automation is expected on the basis of the composite curves to be reached in each of the ship functions studied by the year:

Messing	2019
Sonar	1990
Propulsion	2004
Bridge	2022

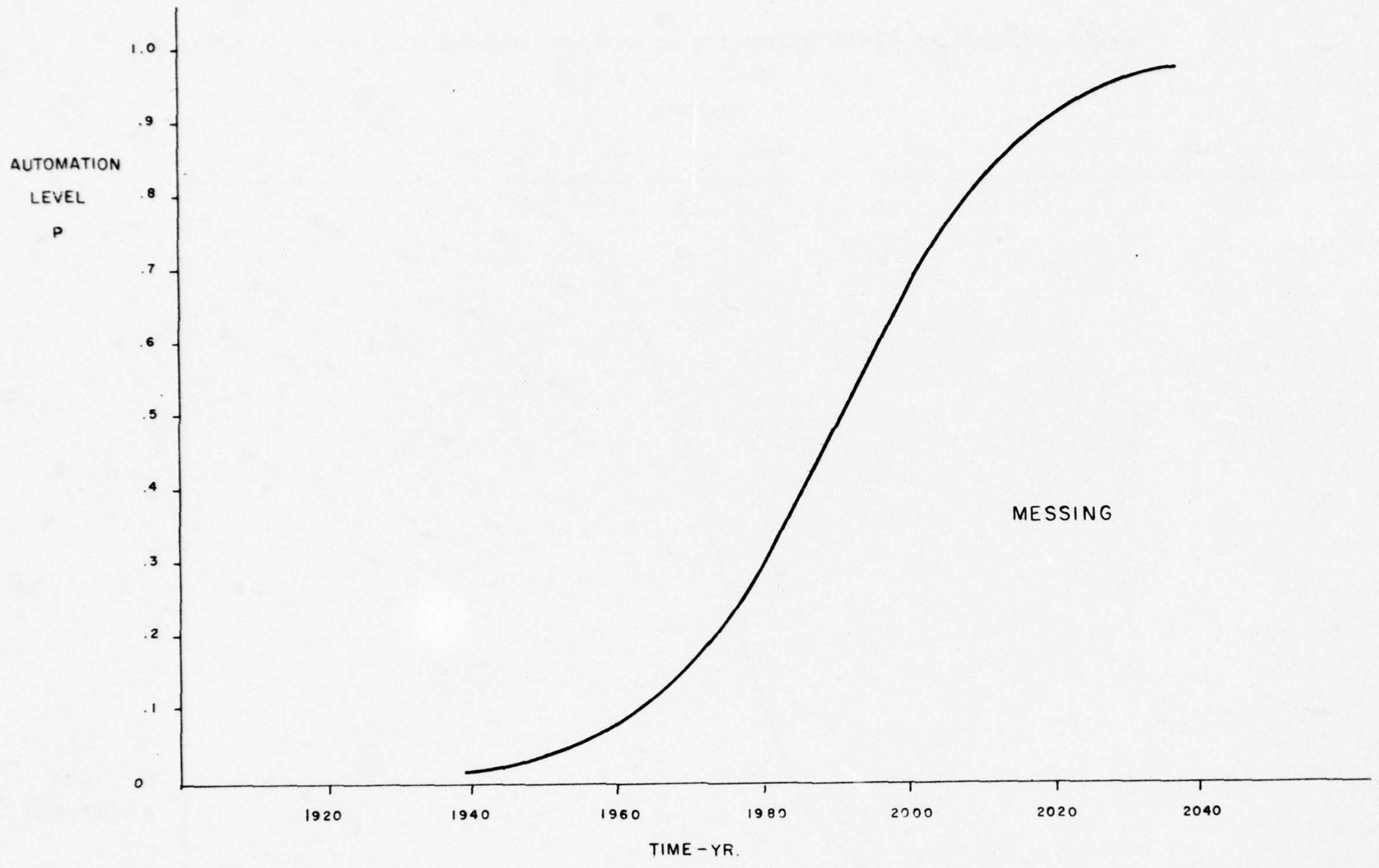


Figure 7. LEAST SQUARES BEST ESTIMATE OF AUTOMATION LEVEL VS. TIME FOR MESSING.

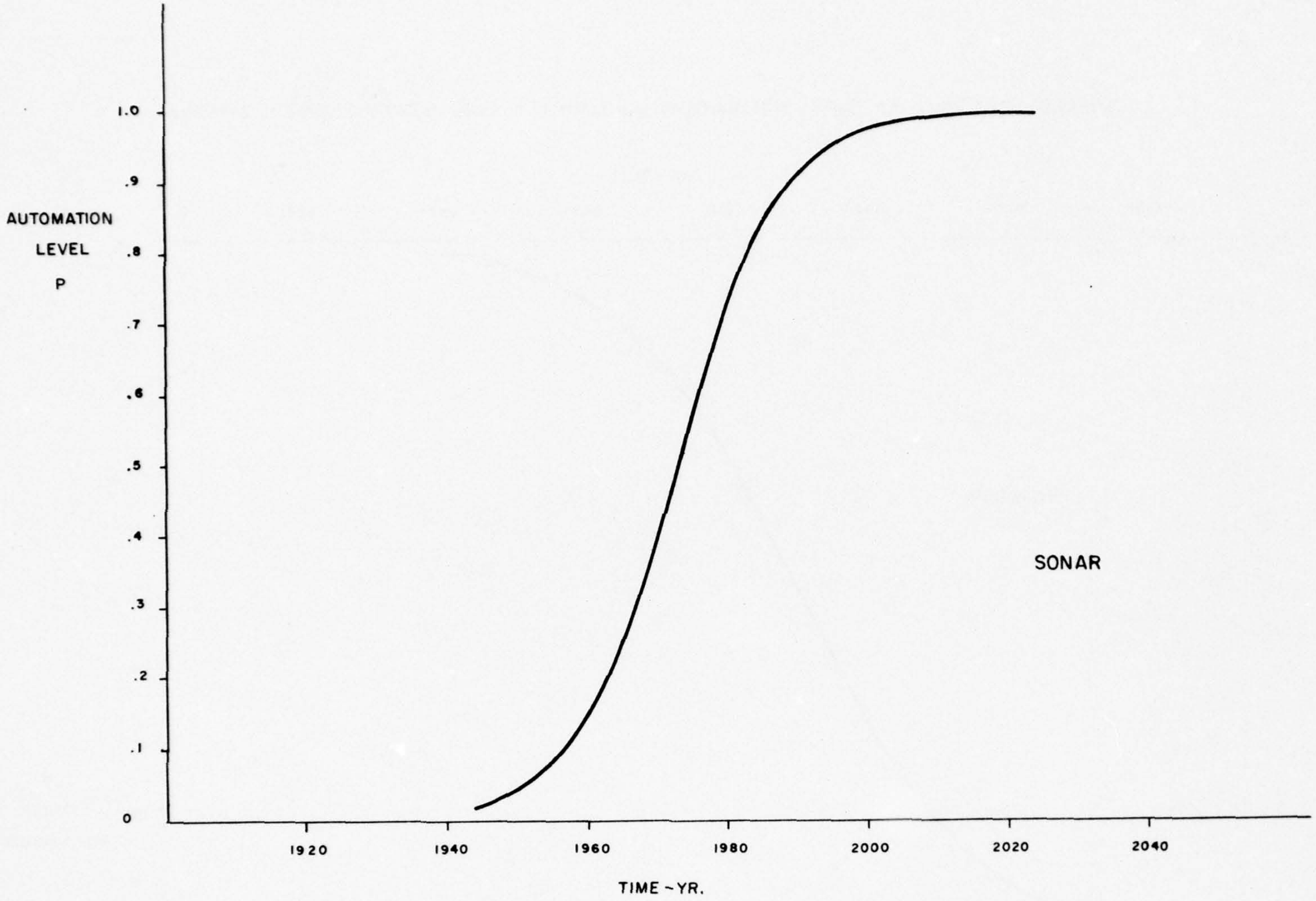


Figure 8. LEAST SQUARES BEST ESTIMATE OF AUTOMATION LEVEL VS. TIME FOR SONAR.

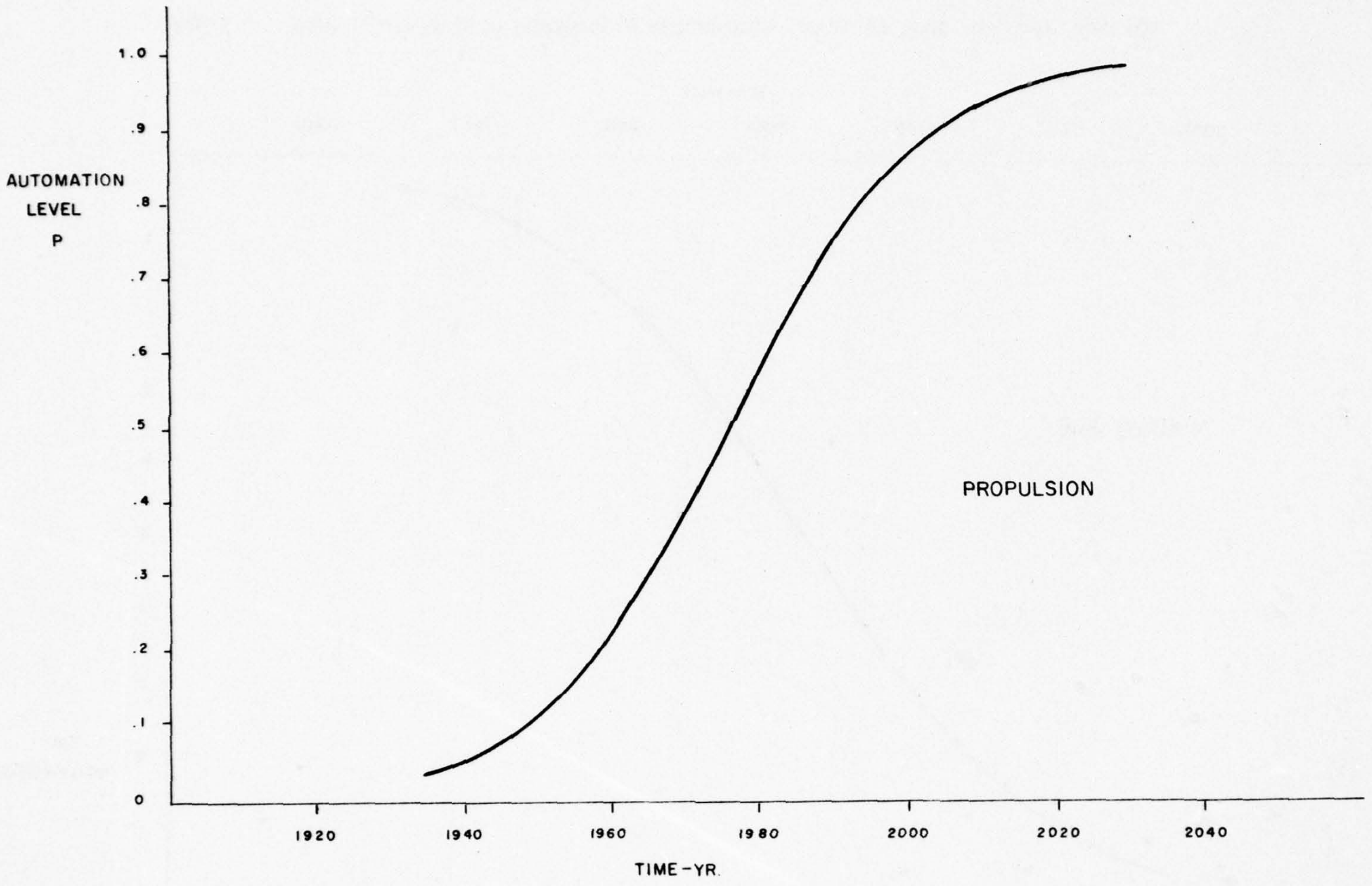


Figure 9. LEAST SQUARES BEST ESTIMATE OF AUTOMATION LEVEL VS.TIME FOR PROPULSION.

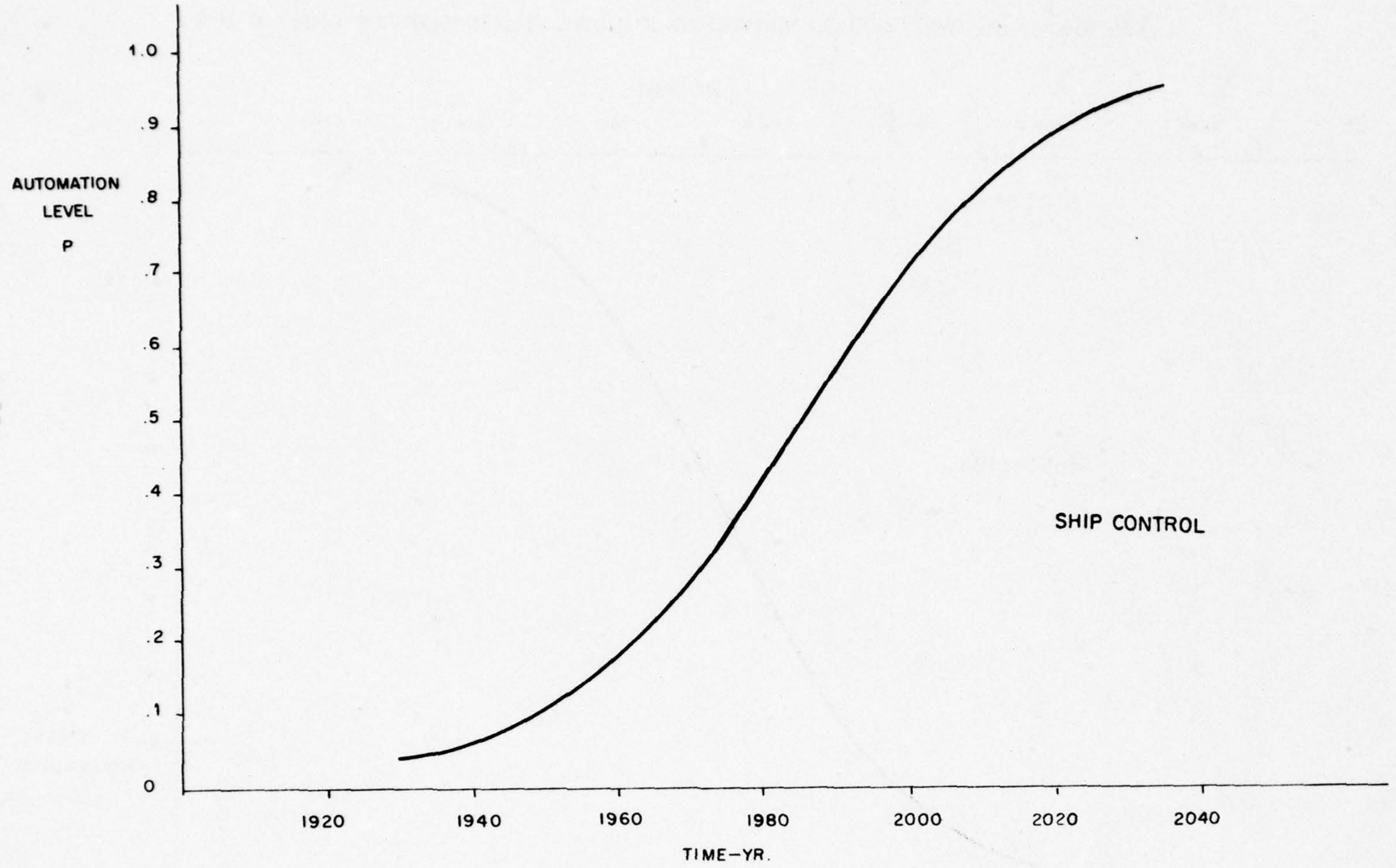


Figure 10. LEAST SQUARES BEST ESTIMATE OF AUTOMATION LEVEL VS. TIME FOR SHIP CONTROL

CHAPTER IV

EXTENDED AUTOMATION LEVEL SIMULATION MODEL

This chapter presents an overview conception of an extended automation level model (EALM) for estimating the manning requirements for future naval ships. The EALM is structured in the form of a digital computer simulation model, and a part of its logic is based on extrapolation along a logistic (Pearl) curve. The logic is also based, in part, on a job complexity construct. This construct is discussed and elaborated in Chapter V.

To accomplish the prediction, a ship is assumed to be organizable into predetermined functions, ISF (such as those shown in Table 2), plus future functions to provide for growth.

Input Data

The EALM accepts a variety of input data describing such run request parameters such as:

- the ship type and its mission
- the range of crew sizes to be simulated and the assumed crew proficiency
- criticality and complexity of ship functions
- reliability data for equipments performing the ship function
- up to 3 manpower allocation schemes
- alternative schemes for extrapolating automation and complexity levels
- output recording detail options

A more detailed list of required input data is shown in Table 9.

Processing

The processing is organized for calculation on up to seven, five year time intervals, i. e., through the year 2010. Data extrapolation techniques are designed to reflect the year 1975 as the baseline.

The EALM is basically a Monte Carlo model in which stochastically determined elements are utilized for representative values of the important variables calculated. Crew sizes of up to 1000 men can be accommodated. A global flow chart of the EALM is presented as Figure 11.

Table 10

EALM Run Input Request Information

		No. of Values	Default Value	Size	Name	Values	
						Min.	Max.
I.	IDENTIFICATION						
	Run identification	1	*	72 ALPHA	RUNID	--	--
	Ship identification	1	*	40 ALPHA	SID	--	--
	Type of ship	1	*	XX	IS	1	10
	Mission identification	1	*	40 ALPHA	MID	--	--
	Type of mission	1	*	X	IM	1	10
	Ship functions identification	14	*	18 ALPHA	SFID	--	--
	Ship function number	14	*	XX	ISF	1	14
II.	CREW DATA						
	Minimum crew per time period	8	*	XXXX	MINC(IT)	25	1000
	Maximum crew per time period	8	*	XXXX	MAXC(IT)	25	1000
	Crew size increment (Men)	1	1	XX	DELTA	1	99
	Proficiency (0=avg.; ±1=±1 sigma)	4x8	0	X.XX	PROF(IP,IT)	-5	+5
III.	BASIC PARAMETERS						
	Shift duration (hrs.)	1	4	XX	ISD	1	12
	Number of first time period	1	1	X	IT1	1	8
	Number of time periods to simulate	1	8	X	NTP	1	8
	Number of iterations	1	10	XXX	ITER	1	200
	Manpower allocation scheme (1-Prorata 2-Criticality 3-Criticality Share)	1	2	X	IMAS	1	2
	Output recording options	3	1	X	ORO(1-3)	0	1
IV.	SHOP FUNCTION DATA						
	Automation levels (use if AL use code=2) 0-Fully Manual 1-Slight Automation 2-Moderate Automation 3-High Automation 4-Fully Automated	8x14	*	X.XX	AL(ISF,IT)	0	4
	Automation level use code 1-extrapolate using best estimate growth curve 2-use specified values of AL	14	1	X	IALUC(ISF)	1	7
	Criticality by ship function and time	8x14	1	X.XX	CRIT(ISF,IT)	0	1
	Complexity by ship function and time	8x14	1	X.XX	CPLX(ISF,IT)	0	5
	Complexity curve use code 1-use complexity values specified 2-no. of selected curve (see Fig. 12)	14	1	X	CCUC(ISF)	1	2
	Time for AL (Fig. 12) curve start	8x14	*	XX	ITAL	1	99
	Time for CPLX (Fig. 12) curve start	8x14	*	XX	ITCPLX	1	99
	MTBF for all equipment in each ship function (1975) (hours)	12	∞	XXXXX	MTBF(ISF)	100	99999
	MTTR for equipment in each ship function (1975) (hours)	12	0	XX.XX	MTTR(ISF)	0	12
	Applicable proficiency relationship 1-future proficiency required increases with more personnel 2-no change 3-future proficiency required decreases	14x4x8	2	X	IAPR(ISF,IP,IT)	1	3
	Average number of man-hours of work required (1975) during a 4 hour shift by ship function for selected ship type & mission type	14 for each mission & ship type	*	XXX.X	AMH(ISF,IM,IS)	4	999
	Current average proficiency by ship function for each proficiency type	4x14	90	XXX.X	CAP(IP,ISF)	0	100
	Sigma for current average proficiency	4x14	10	XXX	SIG(IP,ISF,IM,IS)	0	30

* No default value

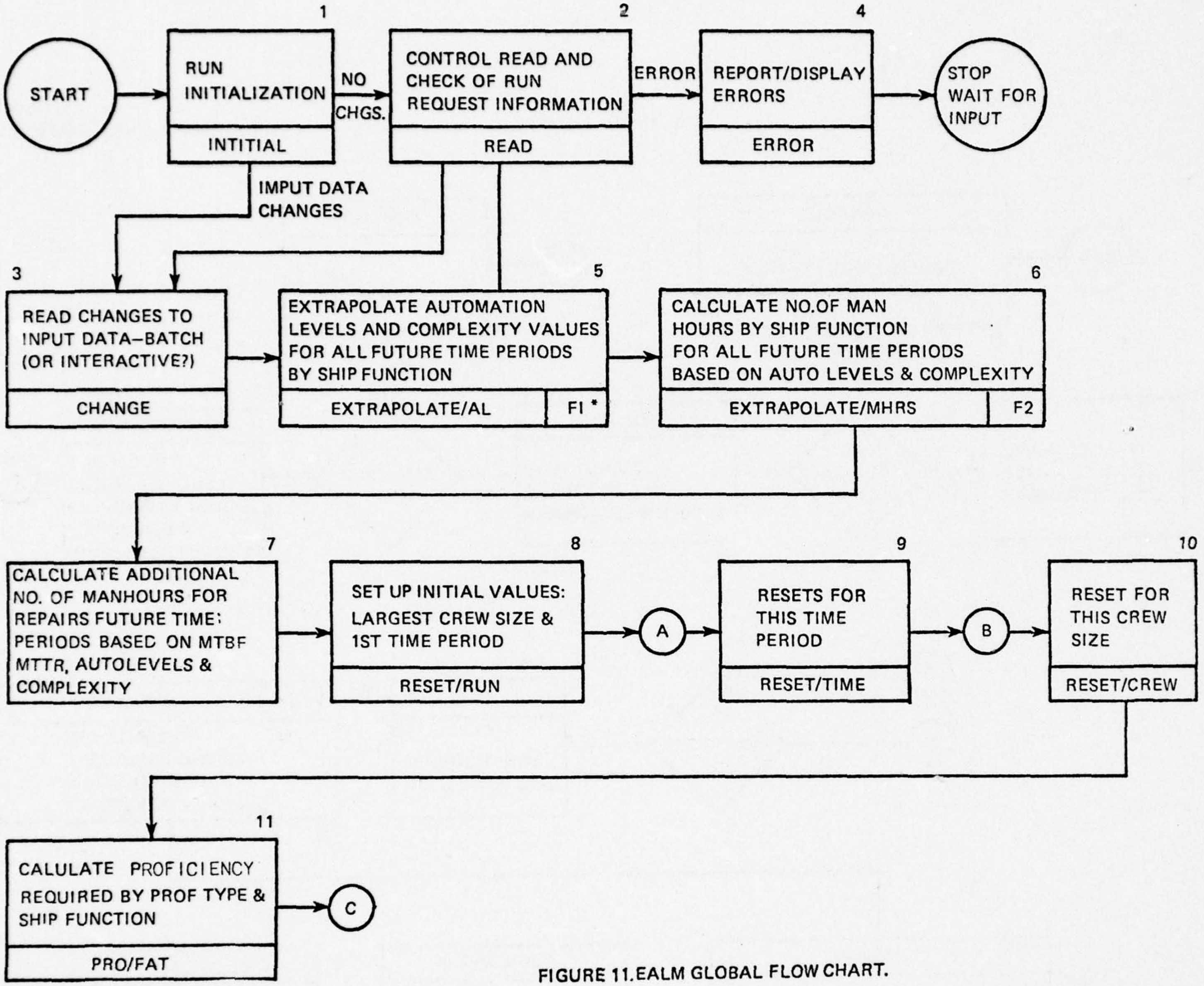
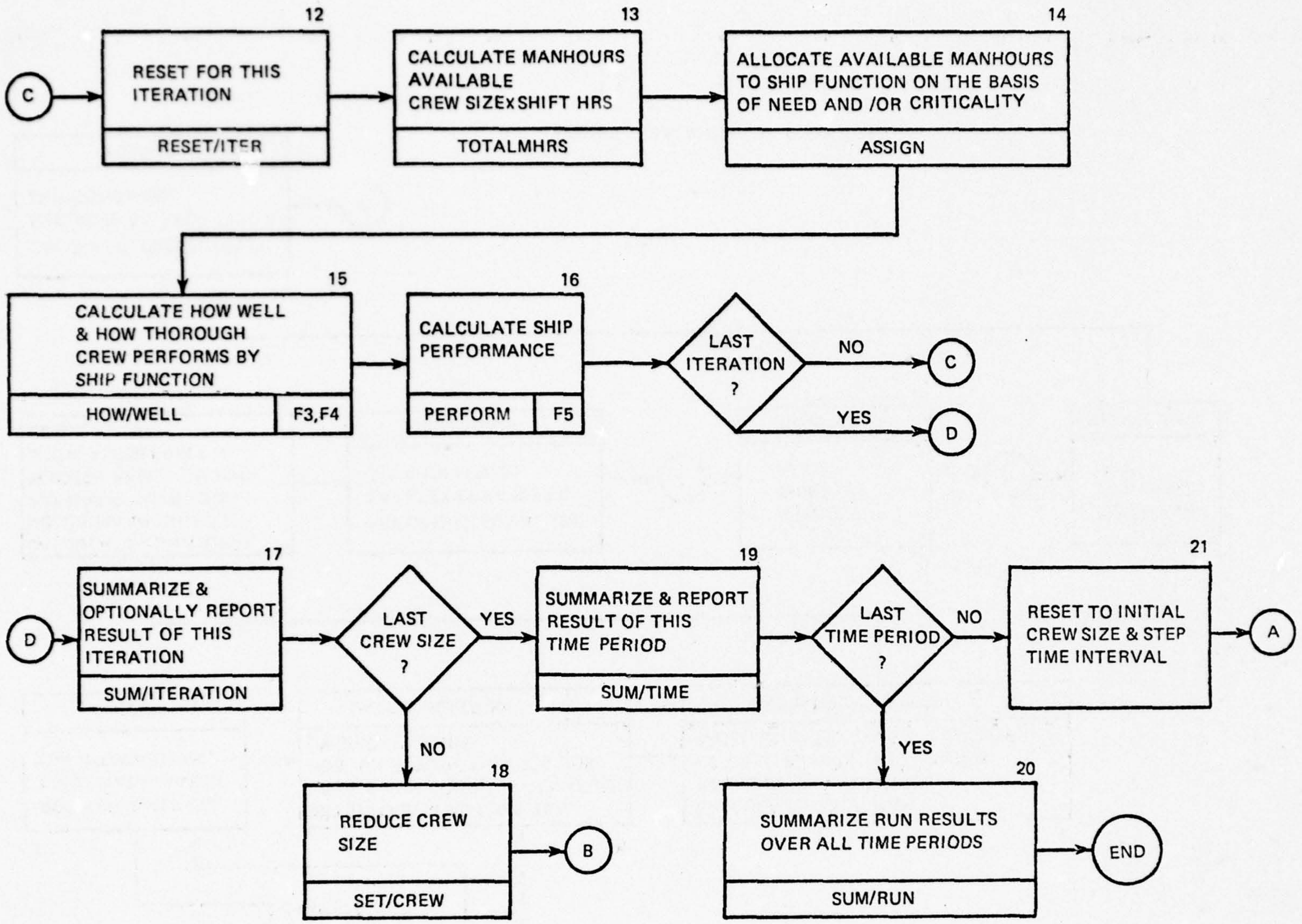


FIGURE 11. EALM GLOBAL FLOW CHART.



*F-NUMBERS REFER TO FUNCTIONS F-1 THROUGH F-5

FIGURE 11 (cont.)

Future estimates of automation levels are made either by extrapolating 1975 data or by using specified input data. The logistic (Pearl) method is used for these projections from which needed manpower levels are determined. This is referred to as F1 (function 1) in Figure 11.

Values for complexity (see Chapter V) may be provided in one of two ways. An individual complexity value for each ship function for each time period may be provided as input, or the analyst may select one of the curve forms shown in Figure 12 to be applicable for each ship function. (When selecting such a curve, the analyst also indicates scaling information.)

The function referred to as F2 in Figure 11 is, in many ways, the key element in the simulation. It is the relationship which shows the procedure for estimating future manning levels on the basis of input and calculated data.

For any ship function (ISF), and time period (IT), by definition of automation level:

$$AL(IT, ISF) = 1 - \frac{MH(IT)}{MHN}$$

where:

AL(IT) = automation level at time T
MH(IT) = manhours required at time IT
MHN = manhours required for no automation

Then:

$$MH(IT) = MAN \cdot [1 - AL(IT, ISF)]$$

and

$$MHN = MH(IT) / [1 - AL(IT, ISF)]$$

But:

MH(IT=1) is the manhours required for automation level $AL(\pm T=1)$, for IT=1 corresponding to 1975.

$$MHN = \frac{MH(IT=1)}{1 - AL(IT=1), ISF)}$$

$$MH(IT) = \frac{MH(IT=1)}{1 - AL(IT=1, ISF)} \left[1 - AL(IT, ISF)\right]$$

For example, if in 1975 (IT=1) AL(1) = 0.2, MH(1) = 40 manhours, and automation level for the year 2000 is AL(5) = 0.6, then

$$MH(5) = \frac{40}{1 - 0.2}(1 - 0.6) = 20 \text{ manhours.}$$

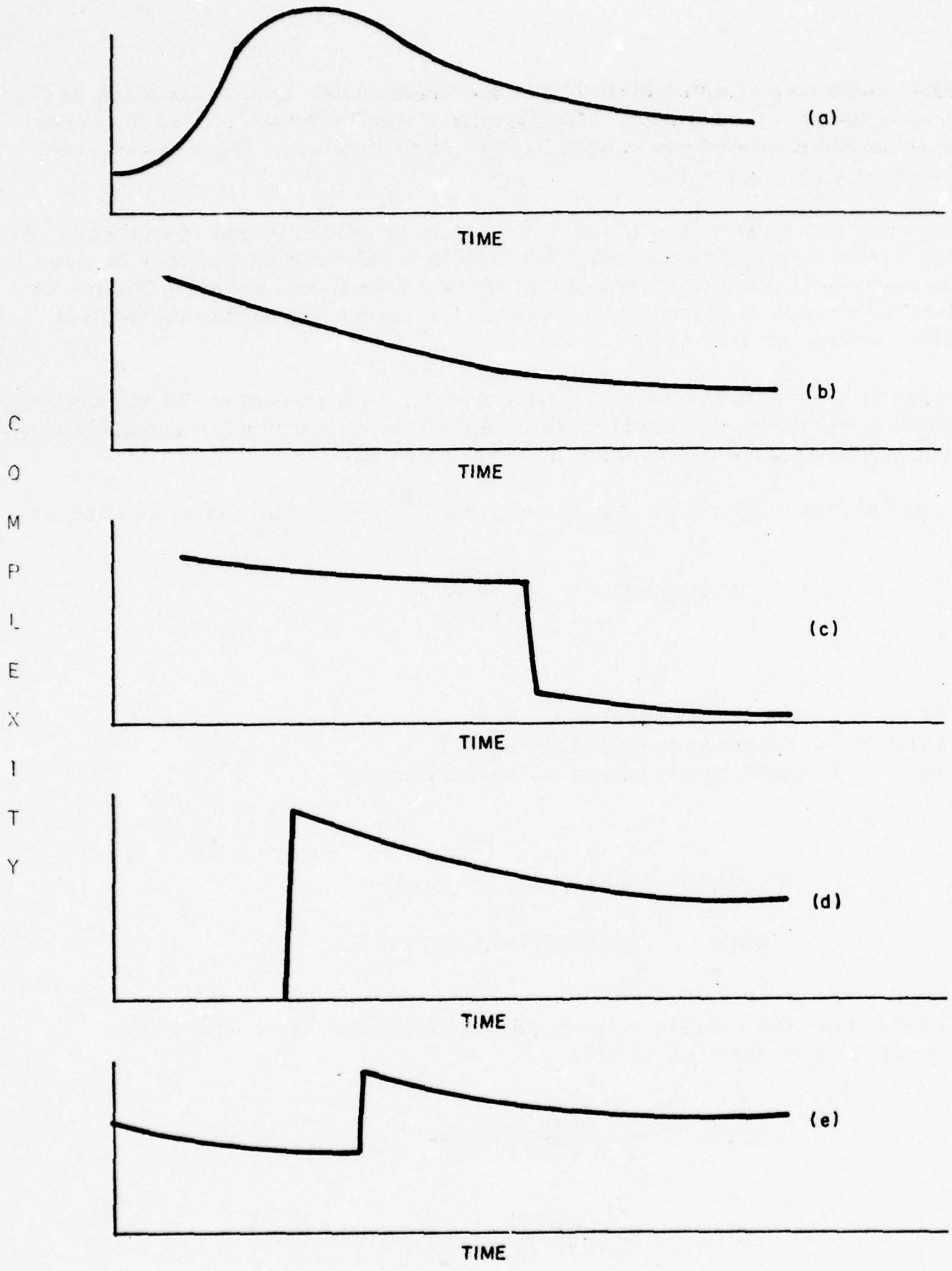


Figure 12. Sample types of curves representing potential complexity trends. Similar types of curves can be input in five year increments or calculated (based on user request) by computer.

Considering the effect of complexity, we have the general condition that MH(IT) should be proportional to complexity, CPLX(IT, ISF). With 1975 as a base year, CPLX(IT= 1, ISF)= 1, or complexity in 1975 is defined to be unity. $\mathrm{CPLX(IT, ISF)} < 1$ implies reduced man hours and $\mathrm{CPLX(IT, ISF)} > 1$ implies increased man hours. Thus for each ship function:

$$\mathrm{MH(IT, ISH)} = \left(\frac{\mathrm{MH(IT{=}1)}}{\mathrm{1\text{-}AL(IT{=}1, ISF)}}\right)\left(\mathrm{1\text{-}AL(IT, ISF)}\right)\left(\mathrm{CPLX(IT, ISF)}\right)$$

A more general form is useful when calculating manhours using some prior year as a base. Here, let t_1 be an early time period and let t_2 be some later period. M_t represents manhours (or numbers of men) at the earlier time, C is complexity, and the form is:

$$M_{t_2} = \left(\frac{M_{t_1}}{1\text{-}AL_{t_1}}\right)\left(1\text{-}AL_{t_2}\right) f\left(\frac{C_{t_2}}{C_{t_1}}\right)$$

The form of $f(Ct_2 / Ct_1)$ is discussed in Chapter V. An adjustment for shift length (ISD) is made by appending another factor--24/ISD.

In the assign program module, three manpower allocation schemes are included. The selection is made by the analyst as input. The problem is one of allocation of a total number of man hours available in some future time period to all ship functions. If the number of man hours required to man each ship function in the specified future year and a criticality value for each ship function are known, the first approach is to allocate pro rata on the number of man hours required. The approach is used when criticality values are equal or if no criticality values are provided as input.

The second scheme accomplishes allocation on the basis of criticality of ship functions:

A. <u>More man hours required than available</u>

1. Assign 50 percent of all man hours required to their respective ship functions, rounded to nearest man.
2. Assign remaining men in order of ship function criticality. Assign all required men for highest critical ship function, next highest, etc., until all are assigned.

B. More man hours available than required

1. Assign all man hours required, rounded to nearest man.
2. Assign the excess man hours on a pro rata basis

C. Criticality share

a. More man hours required than available

1. Assign 50 percent as in A1.
2. Assign remaining men on a pro rata basis, depending on the ratio criticality value for each ship function has to the total of all criticality values.

b. More man hours available than required

1. Like B1 and 2 above.

Two other functional relationships referred to in Figure 11 result in numerical quantification of how well and how thoroughly the simulated crew performs. If too many or too few men are assigned to the ship functions (via model input parameters), the predicted values of "how well" and "how thoroughly" would be expected to be lower than at some optimal value or range. Similar effects can be sought individually or interactively based on the values given other input values. These functions remain to be selected.

The following features are intentionally not considered by the EALM:

personnel crosstraining
ranks and rates of personnel
consumable supplies levels
ships location, distance traversed
crew morale, safety, fatigue, sea state

Output Data

Output results from the EALM would be available in the form of computer printout tabulations showing detail as well as summary information. These would be organized by five year period, by simulated iteration, and/or by crew size to show numerical results including but not limited to:

manpower requirements
man hours - required and assigned
how well and how thoroughly the crew performs
ship performance
future automation levels and complexities of ship functions

CHAPTER V

JOB COMPLEXITY

Chapter IV presented a preliminary overview of a stochastic simulation model for estimating the required manning of future ships. The required manning was drawn from the equation of the form:

$$MHF = \left(\frac{MHN}{1 - AL_{1975}}\right)\left(1 - ALF\right)\left(F(\text{Complexity})\right)$$

where:

MHF = man hours required at some future date
MHN = man hours required to operate the subsystem of concern at the present
AL_{1975} = automation level of subsystem in 1975
ALF = automation level of subsystem of concern at a future date about which manning information is sought
F(Complexity) = some later defined function of complexity of tasks performed by persons manning the station of concern at the future date of concern

In this equation, the automation level at present and that which can be anticipated at some future date can be extrapolated from the Pearl curve or from functions such as those presented in Figures 7 to 10. Current man hour requirements are available in Navy records. However, complexity remains to be defined, and a method for quantifying it remains open. The present chapter presents the methods and results of an attempt to define job complexity. A reasonable result in this regard would provide the required structure for the complexity factor in the future man hours equation. To this end, the methods of multidimensional scaling were used.

Multidimensional Scaling

Multidimensional scaling analysis is a comparatively recent technique for defining or structuring an unordered universe. Originally developed by Richardson (1938), this expansion of basic psychophysical scaling has recently been studied and extended in some detail by several of Gulliksen's students and several others. Gulliksen (1961) summed up his feelings about the value of the methods involved by saying that multidimensional scaling:

> ...is a rather powerful technique for investigating a wide array of situations. The basic experimental question is a very simple one. Despite a superficial appearance of difficulty and unreasonableness, one can get consistent answers and can come up with rather interesting conclusions--some of which verify the results of unidimensional scaling and others of which go beyond. (p.17)

The two central problems addressed by multidimensional scaling analysis are the determination of: (1) the minimum dimensionality of a given set of stimuli and (2) the scale value of each stimulus on each of the dimensions. The specific experimental and computational procedures used have been described in detail by Torgerson (1952, 1958), Messick (1956a, 1956b), and others.

In the present case, the problem becomes that of defining the dimensionality of a set of stimuli which describe operator/maintainer job complexity and the value of the stimuli on each dimension.

As Gulliksen has pointed out, the basic judgment upon which the whole structure of multidimensional scaling analysis rests is very simple. In order to obtain estimates of the "psychological distances" among the various stimuli in a set, most experimenters have asked the subjects (judges) merely to indicate in some manner the degree of overall similarity between each stimulus pair. The methods for obtaining and scaling these distance judgments are generally analogous to the classical psychophysical scaling techniques.

There are two basic methods for obtaining the dimensionality of the judgments --metric and nonmetric. The metric approach assumes that the obtained scale values can be taken as measures of the interstimulus distances in a Euclidean space. The analytical problem then involves determination of the number of axes in that space and the projections of the stimuli on these axes. In these final stages multidimensional scaling analysis uses factor analytic methods. As in factor analysis, for example, the pattern of scale values (loadings) of the stimuli (tests) on each dimension (factor) presumably enables one to attach meaning to, and so to name, the dimensions. This approach was adopted for the present work.

The nonmetric approach avoids the Euclidian distance assumption but seems to involve interpretive difficulty when a number of factors are involved. The nonmetric approach has been largely described by Kruskal (in press).

There are a number of technical problems involved in both metric and nonmetric multidimensional scaling, such as the choice of method for obtaining the interstimulus distance estimates, the choice of spatial model to represent the distances, the determination of the constant required to set the distance estimates on a ratio scale (Messick & Abelson, 1956), and the decision as to whether a transformation of the basic data is required (Helm, Messick, & Tucker, 1961; Kruskal, in press). Basically, however, both the metric and the nonmetric approaches to multidimensional scaling involve the steps of: (1) obtaining a matrix of interstimulus distances, and (2) determining the dimensionality of the space containing the stimulus points.

The metric techniques have been applied to a wide variety of problems. The early work on colors by Richardson (1938) and on relations between nations by Klingberg (1941) have been followed more recently by applications to such areas as attitudes (Messick, 1954, 1956a; Abelson, 1954), personality (Jackson, Messick, & Solley, 1957), jobs (Reeb, 1959), and facial expressions (Abelson, 1962), among others, in addition to further work in color (Torgerson, 1951, Messick, 1956c). The Applied Psychological Services has previously demonstrated the applicability of the multidimensional scaling technique for a number of purposes. Schultz and Siegel (1962) demonstrated the applicability of the technique for avionics technicians, and this study was cross validated by Siegel and Schultz (1963). Smith and Siegel (1967) employed the technique for training program development and training evaluative purposes in the civil defense administrative context. Siegel and Federman (1970) extended the application for evaluating Fleet performance proficiency and Siegel, Schultz, and Lanterman (1964) demonstrated the feasibility of developing Guttman scales of performance on the basis of the factors extracted from a multidimensional scaling analysis.

In areas where the variables are complex and the dimensions unknown or doubtful, it seems particularly appropriate to delineate the variables through multidimensional scaling analysis rather than to establish the dimensions arbitrarily. The research in areas of fairly well established dimensionality, particularly color, has been cited as evidence of the validity of the methods. Messick, in particular, after completing some of this work, concluded that "since multidimensional scaling procedures yielded structures which correlated highly with the revised Munsell system, it would now seem reasonable to apply these procedures for purposes of exploration and discovery in areas of unknown dimensionality" (1956c, p. 374).

Accordingly, it can be contended that the technique has been demonstrated to be applicable in a variety of contexts and that it allows the development of a single, unifying core for describing and defining an unstructured complex.

Stimulus Development

The object of the multidimensional scaling analysis was to identify a set of orthogonal dimensions which could form the basis for defining job complexity. To this end, a comprehensive list of task complexity attributes was required. Three Applied Psychological Services' staff members compiled independent lists of determinants of task complexity. The lists were devised with the goal of completeness, without evaluation of importance, rather than selection of important variables (which would have required placing value judgments and, thus, predefining the variables). The three lists were merged and screened to eliminate redundancy, although no reasonable descriptor was omitted. The resulting 31 items, shown in Table 11, represent the final list after rewriting for form consistency. This form involves statement of the stimulus items as a need or a requirement except where the resulting statement was awkward or contrary to contemporary usage.

Table 11

List of Task Complexity Attributes

1. Requirement for extended periods of training.
2. Tendency toward wide variability in specific tasks to be performed.
3. Adequacy of criteria for evaluating job success or completion.
4. Tendency toward large percentages of allotted work time actually spent in job related activities.
5. Need for fine coordination such as eye/hand coordination.
6. Requirement for large amounts of information to be committed to memory.
7. Requirement for rapid, definite, timely decisions.
8. Requirement for precise body or limb movements.
9. Requirement for depth and completeness of training.
10. Requirement for planning, preparation for, and anticipation of future events.
11. Need for interpreting work procedures for others and assigning specific duties.
12. Need to process a large amount of information.
13. Requirement for making fine sensory discriminations.
14. Need for mental manipulation of data or facts.
15. Requirement for vigilance/sustained attention.
16. Tendency toward variability in task sequence or large numbers of logical branch points within tasks.
17. Need for organizing and scheduling work relative to total requirements.
18. Need for flexibility in reacting to unusual situations.
19. Requirement for interaction with and dependence on other persons.
20. Need for physical strength and endurance.
21. Involvement in many different, seldomly repeated tasks.
22. Tendency for the same aspect of task to be repeated many times.
23. Need to perform several tasks simultaneously.
24. Adequacy of the man/machine interface including design of displays and controls, and workspace organization.
25. Requirement for projection from known data or inferring causes from known effects.
26. Requirement for comparing pieces of information.
27. Requirement for teaching, instructing, or showing others.
28. Tendency toward rigidly fixed task completion times.
29. Involvement of a number of mental skills (e.g., numerical ability, verbal ability, memory, etc.)
30. Requirement to endure physical extremes such as cold, fatigue, discomfort, and poor lighting.
31. Requirement for transforming data or language from one form to another.

Stimulus Booklet Preparation

The multidimensional scaling procedure requires as basic data the "similarity" (distance) of each stimulus to every other stimulus. With 31 stimuli, this involves 465 [(31 x 30)/2 = 465] similarity values. To acquire the necessary data, the items were assembled in booklet form. In the initial preparation of pages within each booklet, a single item was randomly selected from the pool of items. This item was used as the "standard" item to be compared with the other items. After the standard item was selected, the remaining items were randomly sequenced for comparison with the standard. The standard item was then removed from the group of items available for selection. This means that the first item randomly selected was compared with 30 items, then removed. A second "standard" item was then randomly selected, set in form for comparison with the remaining 29 items, and then removed from the item pool. The third randomly selected standard item was compared with 28 items and so on down to the 30th item, which was compared with one item.

In order to have exactly 31 comparisons on each page, the first comparison set (30 comparisons) was presented on the page with the 30th item selected (1 comparison). The second comparison set (29 comparisons) was combined with the 29th set (2 comparisons) and so on for the 15 pages of comparison sets. The shorter section always followed the longer section on a page.

Complete sets of pages were then assembled in random order in booklet form for the required similarity judgments. Each booklet contained 17 randomly ordered pages, 2 pages of instructions, and 15 pages of comparisons. The instructions provided in this booklet are shown in Figure 13.

Raters

Various members of the Human Factors Society who work primarily in the Pennsylvania area were contacted and requested to volunteer their time to complete the task attribute similarity comparison booklets. Those individuals who were willing to donate their time were mailed a stimulus comparison booklet. A number of booklets was hand carried to human factor agencies such as the Army Research Institute for the Behavioral and Social Sciences. Although 25 booklets were disseminated in this manner, some of the recipients found their own schedule too busy to complete the booklet in the time frame which was imposed. Fourteen of the booklets were returned and included in the data analysis. These booklets were completed by individuals representing the following organizations:

Applied Psychological Services
U. S. Army Research Institute for the Behavioral and Social Sciences
General Electric Company
Telecom Systems Inc.
Applied Digital Communications
Naval Air Development Center
Educational Computer Corporation
LaSalle College
Standard Pressed Steel
Burroughs Corporation

JOB DIMENSIONALITY

The purpose of the form is to compare different job attributes. On each page of the booklet you will find one job attribute in a box followed by a list of other attributes. Your task is to:

1. Compare the similarity of the first attribute in the list with the one in the box.

2. Assign a value (from the scale on the right side of the page) which indicates how similar you believe the two job attributes to be. The scale ranges from 0 to 100. A value of 0 indicates absolutely no similarity between the attributes in the box and the listed job attribute. A value of 100 indicates complete similarity (identity) between the attribute in the box and a listed attribute. Other values indicate various degrees of similarity. For example, the values between 1 and 59 indicate different levels of little to moderate similarity and 60 to 99 signify different levels of similarity, from high similarity to complete similarity.

3. Enter the value you selected in the space provided to the right of the list. Your entry should be in the column which contains the value you selected.

4. Repeat this procedure with each job attribute on the list.

5. Continue comparing each job attribute with the one in the box and writing in the appropriate similarity comparison value until all job attributes on the list have been compared with the one in the box.

6. When you have finished with a set (list), go on to the next list.

Figure 13. Instructions for similarity comparisons

You will notice that some pages have more then one list and each list will have a different number of attributes. Each job attribute in a list is to be compared with the boxed attribute that appears at the top of the list. Start comparisons at the beginning of the booklet and work straight through until you are finished. There are no right or wrong answers. The appropriate answer represents your judgment of how similar you think the job attributes are to each other. Don't hesitate to use very high or very low similarity values if they reflect your opinion of similarity.

EXAMPLE

	Little or No Similarity	*Some Similarity*	*Moderate Similarity*	*High Similarity*	*Almost Complete Similarity*
Supervising others	0-19	20-39	40-59	60-79	80-100
Exchanging ideas....................	7				
Taking instructions..................				63	

The first value (7) indicates that the person making the similarity comparisons thought "Supervising others" and "Exchanging ideas" to have hardly any similarity. He wrote in 7 to indicate this. However, he thought "Taking instructions" and "Supervising others" to be highly similar. He entered a value of 63 for this comparison. You may or may not agree with these judgments. When you make your judgments you can enter any number you wish from the scale.

When you have completed the booklet, please check back over every page to make certain that you have placed a scale value alongside each attribute listed.

Figure 13. Instructions for similarity comparisons (cont.)

24. Adequacy of the man-machine interface including design of displays and controls, and workspace organization	Little or No Similarity 0-19	Some Similarity 20-39	Moderate Similarity 40-59	High Similarity 60-79	Almost Complete Similarity 80-100
23. Need to perform several tasks simultaneously					
6. Requirement for large amounts of information to be committed to memory					
2. Tendency toward wide variability in specific tasks to be performed					
19. Requirement for interaction with and dependance on other persons					
8. Requirement for precise body or limb movements					
9. Requirement for depth and completeness of training					
27. Requirement for teaching, instructing, or showing others					
17. Need for organizing and scheduling work relative to total requirements					
29. Involvement of a number of mental skills (e.g., numerical ability, verbal ability, memory, etc.)					
18. Need for flexibility in reacting to unusual situations					
13. Requirement for making fine sensory discriminations					
28. Tendency toward rigidly fixed task completion times					
22. Tendency for the same aspect of task to be repeated many times					
21. Involvement in many different, seldomly repeated tasks					
3. Adequacy of criteria for evaluating job success or completion					
25. Requirement for projection from known data or inferring causes from known effects					
26. Requirement for comparing pieces of information					
11. Need for interpreting work procedures for others and assigning specific duties					
4. Tendency toward large percentages of allotted work time actually spent in job related activities					
16. Tendency toward variability in task sequence or large numbers of logical branch points within tasks					
14. Need for mental manipulation of data or facts					

23. Need to perform several tasks simultaneously.					
11. Need for interpreting work procedures for others and assigning specific duties					
2. Tendency toward wide variability in specific tasks to be performed					
6. Requirement for large amounts of information to be committed to memory					
22. Tendency for the same aspect of task to be repeated many times					
21. Involvement in many different, seldomly repeated tasks					
13. Requirement for making fine sensory discriminations					
27. Requirement for teaching, instructing, or showing others					
14. Need for mental manipulation of data or facts					
18. Need for flexibility in reacting to unusual situations					
3. Adequacy of criteria for evaluating job success or completion					

Figure 14. Sample multidimensional scaling booklet page.

Data Treatment

The mean similarity of each stimulus relative to each other stimulus was determined. This yielded a 31 x 31 raw similarity matrix. In accordance with the method of Stone et al. (1970), the columns were intercorrelated, and the resultant matrix was factor analyzed by the principal components method with orthogonal rotation of the factor matrix in accordance with the varimax criterion (Dixon, 1973 BMD-03M, Revised 9-1-65). Commonalities were estimated at 1. 00 and set in the main diagonal.

A five factor solution seemed most interpretable and to possess the most utility *relative to the goal on hand--defining complexity* terms for inclusion in the manning equation. This solution accounted for 73 percent of the predictable variance. The obtained eigenvalue and cumulative proportion of variance by factor are presented in Table 12.

Table 12

Obtained Eigenvalue and Cumulative Proportion of Variance by Factor

	Factor				
	I	II	III	IV	V
Eigenvalue	11.93	3.84	2.88	2.13	1.98
Cumulative Proportion of Variance	.38	.51	.60	.67	.73

Factor 1--Information Processing

Factor 1 accounted for 38 percent of the variance. The stimulus items loading heaviest on this factor are presented in Table 13, along with their respective loadings.

Table 13

Items with Highest Loading on Factor I--Information Processing

Loading	Item No.	Item
-.87	26	Requirement for comparing pieces of information
-.86	31	Requirement for transforming data or language from one form to another
-.82	14	Need for mental manipulation of data or facts
-.80	29	Involvement of a number of mental skills (e.g., numerical ability, verbal ability, memory, etc.)
-.76	12	Need to process a large amount of information
-.71	6	Requirement for large amounts of information to be committed to memory

The items in Table 13 are all oriented towards the manipulation of information through such cognitive processes as comparison or transformation. Accordingly, the factor was named Information Processing. We note that this is quite a strong factor (Table 12).

Factor II--Psychomotor Coordination

The second factor accounted for 13 percent of the variance (.51 cumulative proportion of variance). This factor seems moderately strong and was characterized by items which seemed to deal with fine or gross manipulation. The stimulus items loading heaviest on this factor are presented in Table 14, along with their respective loadings. In view of the manipulative emphasis of all but the first item in Table 14, the factor was named Psychomotor Coordination.

Table 14

Items with Highest Loading on Factor II--Psychomotor Coordination

Loading	Item No.	Item
.79	24	Adequacy of the man-machine interface including design of displays and controls, and workspace organization
.78	13	Requirement for making fine sensory discriminations
.73	5	Need for fine coordination such as eye/hand coordination
.57	8	Requirement for precise body or limb movement

Factor III--Flexibility/Adaptability

The third emergent factor, which was about as strong as the second, was named Flexibility/Adaptability. This factor accounted for 9 percent of the variance (.60 cumulative proportion). The task complexity stimulus items contributing most to this factor are shown in Table 15.

Table 15

Items with Highest Loading on Factor III--Flexibility/Adaptability

Loading	Item No.	Item
-.89	21	Involvement in many different, seldomly repeated tasks
-.87	2	Tendency toward wide variability in specific tasks to be performed
-.77	16	Tendency toward variability in task sequence or large numbers of logical branch points within tasks
-.68	10	Requirement for planning, preparation for, and anticipation of future events
-.67	18	Need for flexibility in reacting to unusual situations

The set of items shown in Table 15 appears homogeneous in content and seems to involve tasks which require the crewman to act rationally in a variety of unusual and normal situations. The factor was named to reflect this content.

Factor IV--Product and Process Structure

Factor IV seems to reflect duty situations which seem almost bipolar with Factor III. While Factor III seemed to reflect performance in novel situations, Factor IV seemed to subsume highly structured work situations--such as those which might be found in a highly automated factory or on a production line. Factor IV was characterized by "rigidly fixed completion times, " "tendency for same task aspect to be repeated many times, " and duties which need to be organized and scheduled. While it is possible that duties which involve Factor III would also involve Factor IV, this situation does not seem highly probable. Factor IV, which seems to involve tasks which are highly structured and routinized or the production of a very standard output, was named Product and Process Structure. Items loading heavily on Factor IV are presented in Table 16. Factor IV accounted for 7 percent of the predictable variance (67 percent cumulative).

Table 16

Items with Highest Loading on Factor IV--Product and Process Structure

Loading	Item No.	Item
-.85	28	Tendency toward rigidly fixed task completion times
-.55	4	Tendency toward large percentages of allotted work time actually spent in job related activities
-.50	17	Need for organizing and scheduling work relative to total requirements
-.47	22	Tendency for the same aspect of task to be repeated many times

Factor V--Personnel Management and Interaction

The final factor, Factor V, seemed more mixed than the prior four factors. The principle thrust of the factor seemed to involve the need to supervise and coordinate with others relative to an integrated goal. The intuitive relationship of one item loading heavily on this factor, "Requirement for depth and completion of training, " to this factor is not completely clear. It may be that the judges thought that tasks involving such supervision and coordination require greater training. Alternatively, the judges may have experienced a change of point of view relative to the item and may have considered personnel management and supervision to require greater training on the part of those performing the supervision and training. Two other items loaded fairly heavily on this factor which also seem somewhat inconsistent with the attributed essence: "Adequacy of criteria for evaluating job success or completion" (Item 3) and "Need for organizing and scheduling work relative to total requirements" (Item 17). The explanation(s) given relative to the training oriented item may also be relevant in these cases.

Factor V accounted for 6 percent of the total predictable variance to bring the total for all five factors to 73 percent. The items loading most heavily on this factor are presented in Table 17.

Table 17

Items with Highest Loadings on Factor V--Personnel Management and Interaction

Loading	Item No.	Item
-.82	11	Need for interpreting work procedures for others and assigning specific duties
-.81	19	Requirement for interaction with and dependence on other persons
-.80	27	Requirement for teaching, instructing, or showing others
-.64	9	Requirement for depth and completeness of training
-.55	3	Adequacy of criteria for evaluating job success or completion
-.54	17	Need for organizing and scheduling work relative to total requirements

Factor V was named Personnel Management and Interaction to capture the essence of the first three heavily loaded items as presented in Table 17.

Discussion of Results of Multidimensional Scaling Analysis

The multidimensional scaling analysis seems to have yielded an interpretable set of factors which can be employed to define task complexity. The factors seem to be reasonable and acceptable for providing the basis for elaboration of the equation for estimating manning requirements. Four of the factors--Information Processing, Psychomotor Coordination, Flexibility/Adaptability, and Personnel Management and Interaction--seem most concerned with variable input task situations. On the other hand, one factor--Product and Process Structure--seems concerned with fixed input situations. Possibly, two factors--fixed input and variable input--would emerge from a second order factoring or one bipolar factor might emerge from such factoring. Reducing the five factors to two in the equation for predicting manning represents an attractive possibility from the computational simplification point of view. However, for the present, it seems more proper to remain with the five factors which were isolated and to determine the utility of these factors for the purposes on hand.

CHAPTER VI

HAND CALCULATIONAL METHOD FOR PREDICTION OF MANNING REQUIREMENTS

Prior chapters have described the logic for the growth function and discussed computer simulation models vis-a-vis the prediction of manning requirements. It was considered possible that appropriate extrapolation from growth curves would provide a technique for such manning predictions. The availability of such a hand calculational technique would possibly render a computer simulation unnecessary.

This chapter attempts to bring together the formulae, data, and a method for establishing a hand calculational technique for extrapolating manning levels for future ships. All predictions are accomplished using the best estimate growth curves from Chapter III as a vehicle for extrapolating automation levels by ship functions. Accordingly, the technique is best characterized as a trend extrapolative technique as discussed in Chapter I.

Within a trend extrapolative technique, historical data, upon which to base manning level predictions, are, of course, required and are the first topic described relative to the calculations.

Historical Ship Manning Data

Longitudinal data concerning ship control, propulsion, and sonar manning were collected from two sources: (1) interviewees were asked the manning levels in the specific ship function of their experience, and (2) Navy publications were examined to determine officially prescribed manning levels.

Ship system manning data were collected during the course of the interviews which provided the automation judgments described earlier. Each interviewee was asked the number of personnel (officer and enlisted combined) who were on watch on the ship he was describing during normal cruise and under full alert conditions. The obtained manning estimates and the ship on which they are based are presented in Table 18. The data presented are for the normal cruise conditions. Many interviewees indicated that alert manning levels were dependent on the characteristics of the particular alert condition and that it was, accordingly, not possible to make such a judgment. Accordingly, the alert condition judgments were excluded from further consideration in the present work.

The data in Table 18 are presented by class of destroyer, ordered by the year in which ships of that class were first commissioned. The designations shown follow the scheme of Jane's Fighting Ships (Blackman, 1970) for ships commissioned up to that time. Designation of the DD963 as a member of its own class follows current standard practice.

Official manning specifications, applicable to destroyers and submarines commissioned during the period of interest, were also sought. Obtained manning documents fell in the categories: Standard Organization Books (SOBs) and Ship Manning Documents (SMDs).

Standard Organization Books were available at the Navy Historical Library, Washington. The SOBs consulted had been prepared during World War II and showed required manning during alert and cruise for destroyers of the 445 class and of the 692 and 710 classes. These documents reflect approaches to manning of the 1940s for ships which were new at that time.

Ship Manning Documents were examined at the Office of the Chief of Naval Operations, also in Washington. These documents were recently prepared. They reflect current approaches to manning specific ships which are now operational, regardless of the age of the ship.

Data found in SOBs and SMDs are also presented in Table 18 in the "per documentation" column in a manner consistent with the presentation of the interview data in the same table. We note that the "actual" manning as reported by the interviewees and the documents differ considerably. These differences are noted in the error and the percentage error columns of Table 18.

Consider the error inherent in the data for cruise manning levels from Table 18. This can be estimated by comparing the manning estimate from the interviews against those indicated by the documentation. This error and percentage error is shown in Table 18 and is summarized as 28. 9 percent for propulsion, 41. 6 percent for sonar, and 39. 4 percent for bridge. Overall, this averages to 40. 2 percent criterion error, which will be referred to later in comparing manning levels predicted from calculation against "actuals" from documentation.

Job Complexity

As indicated earlier, it seems that some combination of an extrapolation of automation level and of job complexity would provide a sound logic for extrapolating automation level. The results of the job complexity analyses of Chapter V are summarized in Table 19 in terms of the percentage variance which is accounted for by each of the five primary factors. Since a total of 73 percent of the variance was accounted for in this way, Table 19 shows the normalization of these into relative weights which sum to unity. Accordingly, each of the five factors is assigned its importance or weighting factor in the calculation of manning levels on the basis of its contribution to total variance.

Estimates of job complexity were then made relative to each factor by the first author of the present report for each of the three ship functions and for each year for which interview data were available. These estimates, shown in Table 20, used the year 1975 as a standard against which the complexity in other years was estimated or compared. Accordingly, the year 1975 was assigned a value of unity. Values greater than unity indicate greater estimated complexity.

Table 18

Historical Estimates and Their Error

					Cruise Manning Level			
Ship Function	Year of Ship Completion	Ship	Class	Automation Level (Best Fit S Curve)	Per Documentation	Per Interview	Error	% Error
PROPULSION								
	1942	--	445	0.066	22	--	--	
	1945	DD 710	710	0.082	17	20	-3	17.6%
	1959	DD 948	931	0.214	22	20	2	9.1%
	1975	DD 963	963	0.392	15	6	9	60.0%
						AVERAGE		28.9%
SONAR								
	1951	SS 580	Guppy	0.044	1	2	-1	100%
	1962	SSN 594	Permit	0.174	4	3	1	25%
	1975	--	FBM	0.559	4	4	0	0%
						AVERAGE		41.6%
SHIP CONTROL								
	1942	--	445	0.068	5	10	-5	100%
	1945	DD 710	710	0.080	6	8	-2	33.3%
	1959	DD 948	931	0.168	8	11	-3	37.5%
	1975	DD 963	963	0.349	10	8	2	20%
						AVERAGE		47.7%
						OVERALL AVERAGE		40.2%

Form of the Manning Level Equations

In the prior work, and in Chapter V, the calculation of future manhours or manning levels was of the form:

$$M_{t_2} = \frac{M_{t_1}}{1 - AL_{t_1}} (1 - AL_{t_2}) F(C)$$

where M is manning level, AL is automation level, t_1 is some earlier time, t_2 is a later point in time, and F(C) is a multiplicative factor involving complexity. The early research conjecture was to utilize a simple complexity factor of the form

$$F(C) = \frac{C_{t_2}}{C_{t_1}}$$

which would provide for changes in manning as the ratio of the complexity of the two given periods. After the multidimensional scaling analysis, reported in Chapter V, was completed, it was realized that the decomposition of complexity into the five factors identified was important. A complexity factor seemed tenable of the form:

$$F(C) = \frac{WC_{t_2}}{WC_{t_1}} = \frac{0.52CFI_{t_2} + 0.18CFII_{t_2} + 0.12CFIII_{t_2} + 0.1CFIV_{t_2} + 0.08CFV_{t_2}}{0.52CFI_{t_1} + 0.18CFII_{t_1} + 0.12CFIII_{t_1} + 0.1CFIV_{t_1} + 0.08CFV_{t_1}}$$

where WC is the sum of weighted complexity factors shown and in which the coefficients are the weights from Table 19. It was also realized that several alternate forms should also be considered, such as:

$$M_{t_2} = \frac{M_{t_1}}{(1 - AL_{t_1})} \left[1 - AL_{t_2}\right]\left[1 + \log \frac{C_{t_2}}{C_{t_1}}\right]$$

$$M_{t_2} = M_{t_1} \cdot \frac{\left[\frac{(1 - AL_{t_2})}{(1 - AL_{t_1})} + \frac{C_{t_2}}{C_{t_1}}\right]}{2}$$

As a result, these and several other similar forms were investigated as a basis for calculating predicted manning levels. The results were compared against the cruise manning levels shown in Table 18. The last formula given was simple and showed about as good results as any formula on which calculations were made. The results are shown in Table 21. All possible combinations of t_1 and t_2 values were used corresponding to data available. Accordingly, three propulsion, three sonar, and six ship control projections are shown in Table 21.

Table 19

Weighting of Complexity Factors

Factor	Factor Name	Percentage of Variance Accounted For	Importance Weight
I	Information Processing	38	0.52
II	Psychomotor Coordination	13	0.18
III	Flexibility/ Adaptability	9	0.12
IV	Product and Process Structure	7	0.10
V	Personnel Management & Interaction	6	0.08

Table 20

Estimated Complexity Factor Values

Ship Function	Year	Information Processing (CF1)	Psychomotor Coordination (CF2)	Flexibility/ Adaptability (CF3)	Product & Process Structure (CF4)	Personnel Management & Interaction (CF5)	Weighted Sum of Products (C)
Propulsion							
	1945	1.2	1.2	1.2	1.3	1.3	1.22
	1959	1.1	1.1	1.1	1.2	1.2	1.12
	1975	1	1	1	1	1	1.00
Ship Control							
	1942	1.2	1	1	1	1.2	1.12
	1945	1.3	1	1	1	1.3	1.18
	1959	1.3	1	1	1	1.3	1.18
	1975	1	1	1	1	1	1.00
Sonar							
	1951	0.8	1	0.8	1.3	0.8	0.886
	1962	0.9	1	0.9	1.2	0.9	0.948
	1975	1	1	1	1	1	1.0

Table 21

Calculation of Projected Manning Levels

	t1	t2	M_{t1} from table 18	$1\text{-}AL_{t2}$	$1\text{-}AL_{t1}$	C_{t2}	C_{t1}	$\frac{C_{t2}}{C_{t1}}$	Calculated Cruise Manning M_{t2}	Documentation Estimate of t2 Cruise Manning	% Error
PROPULSION											
	1959	1975	22	.608	.786	1.0	1.118	.894	18.3	15	22.2
	1945	1975	17	.608	.918	1.0	1.218	.820	12.6	15	16.1
	1945	1959	17	.786	.918	1.118	1.218	.918	15.1	22	31.4
										MEAN	23.2
SONAR											
	1951	1975	1	.441	.956	.886	1.0	1.129	.8	4	80.1
	1951	1962	1	.826	.956	.886	.948	1.070	1.0	4	75.8
	1962	1975	4	.441	.826	.948	1.0	1.055	3.2	4	20.6
										MEAN	58.8
SHIP CONTROL											
	1942	1975	5	.651	.932	1.0	1.12	.893	4.0	10	60.2
	1945	1975	6	.651	.920	1.0	1.18	.847	4.7	10	53.3
	1959	1975	8	.651	.832	1.0	1.18	.847	6.5	10	34.8
	1942	1959	5	.832	.932	1.18	1.12	1.054	4.9	8	39.2
	1945	1959	6	.832	.920	1.18	1.18	1.0	5.7	8	4.8
	1942	1945	5	.832	.932	1.18	1.12	1.054	4.9	6	18.9
										MEAN	35.2

Table 22 summarizes the average errors of these estimates (percentage error comparing projection with documented manning levels) and also compares these projections with the "error" (difference between personnel levels as reported by interviewees and as derived from documentation) of the available criteria.

Table 22

Error of Prediction Compared with Criterion Error

	Percentage Error	
Function	Calculated	Criterion Error
Propulsion	23.2	28.9
Sonar	58.8	41.6
Bridge	35.2	47.7
Mean	38.0	40.2

Table 22 suggests considerable error in the hand calculation projections. However, since the criterion error is high, it may be that the hand calculational method does about as well as can be anticipated under the circumstances. Two points of view can be taken. One point of view is that if one has no target, he has little change of hitting it. The other is that with a broad target, there is little chance of missing it. Quite obviously, a predictive method cannot be expected to be more precise than the criterion it aims to predict. Certainly, the hand calculational method yields results which are about as precise as the results which are yielded by going to various available sources.

CHAPTER VII

SUMMARY AND DISCUSSION

Summary

The present study was conceived as an exploratory investigation into technological extrapolation relative to manning requirements for advanced, post year 2000 ships. No technique has heretofore been available for achieving this goal.

Manning level was believed to be linked to the level of automation of ship functions. Accordingly, a technique was sought which would allow projection of the automation level of various ship functions through the time period under consideration. To this end, the technique originally developed by Pearl was exploited. The technique has been found useful for projecting growth functions in a wide variety of situations and there was considerable reason to believe that it would possess merit for projecting the growth of automation in various Navy ship functions.

Growth curves were developed on the basis of estimates of experienced Navy personnel of the level of automation of a selected set of ship functions at selected points in time. The growth curves, so derived, did not converge in all cases. While lack of convergence may have been anticipated, a simple growth function was sought which would best represent the automation growth for each ship function involved. To this end, a least squares best estimate technique was developed and employed to represent the automation growth of the ship functions involved. The automation levels projected by the least square fit seemed reasonable--but, who can tell?

Since the ultimate goal of the work was to predict manning level, two alternate methods for such predictions were entertained: (1) a digital simulation technique employing the growth curves as a part of its logic, and (2) a hand calculational technique based largely on data yielded by the growth curves.

The digital simulation model was outlined in terms of its input, logic, and anticipated output.

The hand calculational technique was fully developed and applied. Because it was believed that manning level is both a function of automation level and the complexity of the tasks that people must perform in a system, a method for defining task complexity was sought. To this end, a multidimensional scaling analysis of task complexity was completed, and five complexity factors were identified. These were employed, in conjunction with Pearl curve extrapolations, to calculate predicted manning levels at various points in time for which two types of "actual" manning data were available.

The predictions did not appear to be highly acceptable, but it was not possible to say how unacceptable the predictions were. This is because the predictions agreed with the criteria about as well as the two available criteria agreed with each other.

Discussion

What then may be said about the present status of manning projection, at least within the bounds of the present study?

The work produced a working hypothesis, and the logistic growth principal still seems as sound, relative to automation growth, as any other working hypothesis with which we are aware. It may be that a firmer result would have obtained if ship functions had been defined on a total ship basis rather than on a ship station basis, e. g., all shipboard electrical work, all shipboard facilities maintenance, all shipboard electronic work, all stores loading, etc. However, decisions must be made in the day-to-day conduct of a program, and one can only say that he made the best decision on the basis of the information available at the time.

The error in the hand calculational technique may be quite acceptable for some purposes. Moreover, the accuracy obtained may be as much as one can expect in view of wide variation (as indicated by the criterion data) in actual manning.

The computer simulation was never programmed. Accordingly, we cannot assess its merit except conceptually. Some would say that such a technique represents the only way to perform such projections. The analyses reported in Chapter I (Table 1) support contentions favoring the usefulness of such a technique in the present instance. Further development of such a model seems warranted.

The present set of studies seems to have cast some light on problems relative to manning projections in the Navy and to have provided some progress and knowledge relative to these problems. Technology will continue to advance, and the quest for improved methods for predicting such trends will continue. Sound methods for projecting manpower requirements will continue to represent a need for industry, government, and the military.

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APPENDIX

The Ship of the Future as Extrapolated from Technological Advances

This appendix presents an educated technical estimate of characteristics of ships for the Navy which can be expected to go down the ways about the year 2000. The authors have been optimistic in considering potential for future advances and have assumed continued financial support at present equivalent levels.

Advances in technology may be expected to produce automation level changes such as those shown in Figures 7 through 10. These advances will remove needs for performing many tasks--particularly in the system maintenance, facilities maintenance, and messing functions. It therefore appears likely that future naval ships can be smaller and more lightly manned than are ships of today's Navy. Automated data processing advances could, similarly, remove much of the present human information processing.

As we move toward the twenty-first century, major advances are also expected in the materials from which ships are constructed, as well as in the interrelated electronic, communications, and computer areas. These advances could allow, as well as stimulate, the reduction in ship size and complement coupled with an increase in vehicular speed, defense capability, and offensive capability.

One factor promoting the trend to "low value ships" is the projected availability of inexpensive precision-guided weapons which will virtually assure that every shot hits its target, even at extremely long range (Defense, 1977a).

These and other special technological advances which have been anticipated to occur in various technological areas during the balance of the twentieth century are described in this appendix. They represent a more thorough answer to the question: what are the reasons for the substantial increase in automation levels as projected?

Materials

Current ships are primarily constructed of steel, which seems to possess at least three advantages as a structural material: (1) it is strong and relatively inexpensive (King-Hele, 1970), (2) it is readily worked and welded, and (3) it has defensive armor capability. However, steel is heavy and corrodes rapidly in naval applications. Substitution of novel materials may reduce maintenance and weight of future ships. King-Hele foresaw steel as becoming "stronger and tougher" through addition of new additives by the end of this century, and expected improved coatings to combat corrosion more effectively. Crowdon et al. (1974) described cathodic methods which are capable of dramatically reducing corrosion damage.

A structural steel was recently advertised which requires no protective coating since its oxidation is self limiting, i. e., the tough rust layer which quickly forms was claimed to protect the balance of the material from further rusting. It seems logical that a similar steel might be developed for use in the marine environment in the future.

Substitution of novel materials may reduce maintenance and weight of future ships, yet structural strength could increase. According to King-Hele (1970), beryllium and titanium may replace steel and aluminum in applications where strength combined with minimum weight is required. While the density of aluminum is one-third that of steel, Prehoda (1967) pointed out that the density of beryllium is two-thirds that of aluminum, while it is only one-third the weight of aluminum in terms of strength-to-weight ratio. At present, beryllium is expensive, difficult to work, and its dust is highly toxic. Prehoda stated that the first of these problems will be alleviated with increasing use, and substantial progress has already been made toward solving the second and third problems. Titanium is already heavily utilized in aircraft, as well as in consumer products, where strength and light weight are important. This holds despite titanium's expense and the requirement that titanium welding must be performed in an inert environment.

Advances may also be expected in nonmetallic materials. Rosen (1970) described a honeycomb paper material which is already suitable for construction of truck trailer bodies and marine cargo containers. This material, if employed in ship construction, would also yield a considerable saving in weight.

Prehoda (1967) anticipated improved fiber glass materials and improvement in the strength of bulk glass as well. Prehoda also described the theoretically available properties of ceramic materials, materials which combine ceramics and metals, and mixtures of normally nonalloying metals. He stated that technological capabilities, especially in high temperature applications, will be advanced greatly if sufficient research funds are made available in this area.

Composite materials, in which fibers or whiskers of boron or graphite, are embedded in a "matrix" of plastic or metal, are now in commercial use. Prehoda stated that the reinforcing whiskers, due to their perfectly pure crystalline structure, are up to 20 times stronger than the same material in its normal form. He expected composite materials to exhibit up to one-third of the strength of the individual whiskers or nearly seven times the strength of the normal material, and indicated that yet to be developed "... high temperature composites will revolutionize earthbound, airborne, and space-oriented propulsion systems."

Communications

A massive increase in the volume of communications in the early twenty-first century seems entirely tenable. Naval ship communications will certainly participate in this growth and subsequent crowding of frequency bands. According to Pierce (1967), the advances which will shape future communications will be the cheap broadband transmission of information and the availability of low priced, highly complex, reliable communication terminal equipments. Advances in microelectronics could help to augment these developments. Considerable activity is already underway in the development of communication systems which operate at the higher radio frequencies (Brader, 1977).

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The higher frequencies possess greater capacity because bandwidth x time equals a constant for transmission of a given message (Cherry, 1966). It is this relationship which leads to the interest in laser communication.

However, atmospheric conditions may interfere heavily with high channel capacity communication links. Microwaves longer than those in the extremely high frequency band are absorbed by rain (Pierce, 1967), and later communications may only be employed in a clear atmosphere which will not scatter the transmitting beam (Pierce, 1968).

According to Pierce (1968), laser communications circuits will yield circuits of "almost unlimited bandwidth" when: (1) modulators having the necessary bandwidth are developed, (2) detectors are available for long wavelength laser transmissions, and (3) sufficiently accurate automatic aimers and re-aimers are developed.

Pierce (1968) foresaw a time when all frequencies will be crowded with data, voice, and picture transmissions. Some burden may be relieved by transmitting instructions for computer reconstruction of a visual image rather than transmitting the entire image line by line in facsimile fashion (Pierce, 1967), or by transmitting only those picture units which have changed since the previous scan (Chynoweth, 1976). A method for automatically analyzing speech into a code which may be very efficiently transmitted and then resynthesized to speech has been available since the 1930s (Cherry, 1966). These and other methods of information compression will certainly be required to prevent overloading of even the very high capability communication channels of the future (deCarlo, 1968).

Computers

Major advances in computing technology can also be expected by the year 2000. Chynoweth (1976) indicated advances in miniaturization of solid state electronics. He anticipated new production techniques to reduce the width of conductor strips by a factor of ten. Bubble domain memory units of 500, 000 bit capacity have already been built which, including associated circuitry, occupy ". . . a few cubic centimeters (and represent) a considerable reduction in volume (and weight) from that required to achieve the same capacity using magnetic drums or disks" (Chynoweth, 1976).

Chynoweth projected similar reductions in the volume of memory units employing charge, coupled devices. In addition to a tenfold reduction in volume, he predicted a hundredfold reduction in operating power. Similarly, Josephson junction devices represent another possible method for performing logic operations "close to fundamental lower limits in power requirements" (Chynoweth, 1976). Power economy is important both for minimizing shipboard generating requirements and for relieving system cooling problems.

Toffler (1971) anticipated that in the twenty-first century, computers with the power of a present-day IBM System 360 will fit in the palm of one's hand and will cost the equivalent of present-day $100. This small size and cost will contribute toward increasing computational speed and utilization on an expanded set of shipboard tasks. King-Hele (1970) pointed out that the ultimate limit to computing speed (the speed at which impulses travel within a computer) will limit computing speed to 1000 times that of current machines. However, if a limit of computing speed is near, we should expect programmers and computer designers to circumvent the problem through heavier utilization of parallel processing. A variety of techniques are already being implemented in multiprocessing, parallel processing, and distributed processing architectures. New executive computers could integrate the various outputs, much as the executive routine does in current practice. Such a programming approach is highly similar to the concept of "distributed intelligence" in which several independent computers work on a given task (Vacroux, 1975).

Withington (1975) indicated that programming and debugging should be performable in the 1980s at twice today's rate. Higher level languages may be used, and interactive command languages should aid users in communicating with systems. Advances in structured programming techniques, interactive syntax, and automatic logic checking may additionally streamline programming. [For example, the PROSE language (Thames, 1975) a new programming language, allows automatic solution of calculus problems.]

Propulsion

Ships of the early twenty-first century will probably possess various types of power plants including nuclear, diesel, and gas turbine. Final drive will be gear or electric, possibly utilizing superconductor technology in the latter case (Edelsack, 1975). Regardless of the specifics of the plant, uniform characteristics should include faster response to throttling, as well as shorter start-up time and a higher degree of automation.

These quick response characteristics may prohibit manual control--a trend evident in current destroyer turbines. Human monitors will be unable to detect and respond to events associated with these plants in a timely manner (Rasmussen, 1968). Computer monitoring and control of air-fuel ratios, pressures, temperatures, speeds, etc., should be the rule--as is already evident in modern turbine destroyers. Responsibilities of engineering personnel may generally be limited to conducting walk-through inspections (since sensors cannot be located to detect every possible leak, check the condition of every filter, etc.), and standing watch at status panels--as is also the current practice in advanced destroyers.

Engineering personnel will probably be trained in casuality control procedures so as to be able to maintain power and control under all possible conditions, using manual overrides, if necessary.

According to Crowder et al. (1974), future ship hulls will be unlike the traditional full-displacement destroyer-type hull. Crowder contended that reduction of wetted area and decoupling from the sea surface will allow increased speed, increased speed in sea state, and increases range. Air cushion vehicles, various types of planning hulls, hydrofoils, and hybrid forms, each with their particular advantages and liabilities, may become the dominant hull form of combatant ships.

Sensors

Monitoring a broad spectrum of electromagnetic as well as acoustic energy should be an important part of the mission of every year 2000 combatant ship. Marshall (1974) foresaw the capability for Pentagon officials to oversee immediately operations at any point on the globe, using high capacity, secure, audio, video, and data links. Through a modest extension of this capability, sensor data from all ships could be relayed to central shore-based computers where events could be monitored on a global scale.

RPVs may be heavily utilized in such monitoring. As Crowder et al. (1974) pointed out, an RPV using radar or active sonar will not divulge the location of its mother ship. Also, some sensors, such as sonar, cannot function from a ship moving at high speed. Accordingly, in the twenty-first century, RPVs may remain in operation throughout entire ship missions. The RPVs may operate from the sea surface, as well as while airborne. Data may be relayed to the ship by radio or, for added security due to its line-of-sight characteristics, by laser. RPVs at altitude could monitor radio transmissions. RPV mounted radar may similarly have an enhanced range.

Processing targets could be largely automatic. Classification [illegible] contacts may be done automatically or in a computer-aided fashion employ[illegible] comparison of target signatures with a library of known target signatures, as suggested by the current AN/BQQ-5 system. The frequency with which full shipboard classification procedures will be required may, however, become very low if through high capacity communication channels, shore-based computers receive information relative to every target detected. by any ship, worldwide, and relay this information to ships as appropriate.

Detection of targets through IR sensors may become critical. Missiles and RPVs will be small, designed to produce the minimum possible radar echo, and covered by microwave absorbing materials as is the current practice. Electrical counter measures against radar may be greatly advanced, but masking or disguising of the heat of an RPV engine or of a fast-moving missile may be very difficult. Thus, IR scanners may be the most effective detectors of certain types of traffic. The advantage to searching for IR energy from behind approaching vehicles makes the use of remote IR detectors especially important.

Following current human factors emphasis, system operators will probably be responsible for deploying RPVs when needed. Again, following current practice, it may be expected, however, that computer prompting will be used to remind operators to recall a sonobuoy which is being left behind, to optimize placements relative to temperature gradients, sea states, etc. Automatic alarms may be installed which will be activated if any RPV is closely approached by another vehicle.

RPVs may be heavily used for reconnaissance. Reconnaissance RPVs are now operational, and new ones are under development. Data collected via visible light, IR, laser scanning, etc., might be recorded digitally in the year 2000 and relayed to the ship in real time or in blocks for presentation on CRTs.

Human monitoring of passive sonar displays may still be required since targets should still be sought at the 50 percent detection level (Fridge, 1976). However, investigation of possible targets through the use of RPVs should greatly ease the task of the display monitor.

Selection of D/E angles, pulse parameters, integration times, etc., will probably be computer aided. Sonar systems configuration may be partially automated, and the availability of a computer recommendation should lessen the chance of choosing an inappropriate configuration.

Personnel may be required for monitoring IR detection displays, as well. The IR operator will probably make adjustments to settings analogous to those of the passive sonar operator and may receive computer prompting similar to that of the sonarman.

All sonar, MAD, IR, and radar data should be correlated by computer. A single, integrated display, an extension of that foreseen by Fulton (1974), will probably be on hand to present all information relevant to targets above, on, or below the surface. This single, integrated display will be further detailed in the discussion of the Combat Information Center.

Due to the volume of information expected to be available from central computers, classification tasks will probably be decision aided. After a target is once identified, its track may be projected at shore-based computers, and any ship will be notified of the target's approach to its detection area. Upon detection, the target could be automatically identified with a centrally assigned tag which might be the same as long as the target is under surveillance.

Weapons

Weapons of the year 2000 should be effective at longer range, highly automatic, and of novel design by today's standard. It does not seem unreasonable to anticipate an extension of the current capability to deliver weapons by RPV.

Flight of military aircraft such as the B-47 by remote control is a nearly routine practice (Finegan, 1977). Takeoffs, missions, and highly accurate landings are performed by controllers on the ground or in adjacent aircraft. One may project remote piloted aircraft, suitably equipped with television cameras, etc., which may perform missions in the year 2000, which currently require manned aircraft. RPVs may be dispatched to intercept vehicles, transmit optical pictures of the target to a base, and escort the vehicle away or destroy it. Even current RPVs can maneuver with the intensity of today's small missiles, which generate G forces not tolerable by humans. They do not require the heavy and costly life support systems, armor, or ECM equipment which manned aircraft need for protection of the pilot.

Weapons may include ballistic and cruise missiles. Both automatically guided, high powered lasers (Defense, 1975), and programmable homing torpedoes, including ASROC types.

It seems that there will be little need for traditional guns or unguided missiles in the Navy of of the twenty-first century.

The laser weapons mentioned are likely to be used primarily for defense against close-in targets and, accordingly, are likely to be under automatic control. If a ship's own sensors detect that it is under laser attack, its own lasers should be fired against the attacker immediately. In this case, time for human evaluation and decision is not available (Denikoff, 1976).

Longer range strategic weapons will probably be automatically programmed, but will probably be fired through a highly safeguarded manual procedure, much like the the current ballistic missile practice. In addition, there appears to be little reason to suspect that the political consequences of inadvertent firing of a strategic weapon will not remain a constant issue.

It seems probable that loading/unloading small missiles and torpedoes will be performed by men using labor-saving machinery. These tasks can be expected to be similar to currently required activities.

Air Operations

Despite the advent of the RPVs, manned missions should probably remain with us. Search, rescue, and transportation, for example, should remain manned. It is anticipated that shipboard handling of manned aircraft will be similar to current practice, except that labor saving equipment may be used more extensively. Movement of aircraft, between flight checks, refueling, etc., should also be facilitated through provision of superior work-aiding machinery, and lightening of equipments in general. Automatic landings of large aircraft is a reality of present. Extension of this technology to shipboard landings may be expected to allow an increase in the reliability and safety of landings of future aircraft aboard ship.

Control of RPVs should be computer-aided. Operators should be able to "fly" RPVs from simplified airplane-type controls at the sensor operator's console. Even in current RPVs, an operator can designate a location to which an RPV should proceed, and the RPV will be "flown" there and back by the computer (Defense, 1977).

The use of remote piloted vehicles may call for a variety of skills and activities not present in the current Navy. Recently completed analyses at Applied Psychological Services indicate that RPV control, recovery, and servicing require some skills which are quite novel and others which are required today. Control of RPVs during launch and recovery may constitute a new set of tasks unlike presently needed activities. Personnel may need to be trained specifically to control RPVs during launch and recovery.

Automatic takeoffs may, in fact, be performed. However, human monitors may supervise takeoffs and will control RPVs during landings at the ship. The human RPV specialist may control RPVs close to the ship only. At distances of over a few hundred yards, RPVs may be directed by sensor operators or by the ship's main computers. This represents the design philosophy of RPVs currently under development.

Return of RPVs to storage areas, checkouts, refueling, etc., may be performed in relatively traditional ways. Checkout of RPVs should be done by computer --following the current trend toward automatic test equipment. Only parts and module replacement will be performed aboard ship. The need for repair should be rare due to use of superior bearings, materials, etc., as described elsewhere.

Communications

If the interaction with shore-based computers becomes a reality, as described earlier, then a major part of the mission of every naval ship may be to function as a node in a global information network. Encryption and rapid frequency shifts will probably be used to help maintain communications security.

In addition to data, large volumes of voice, video, and message information will probably be involved. Ship commanders may be able to communicate with higher level commanders directly and with no greater delay on message distribution than in transmission. According to Marshall (1974), the individual ship should not be "on its own." Each significant event involving a ship may be relayed to all ships to whom the event is relevant. If interaction with shore based computers becomes a reality, ship commanders could be made aware of approaching targets.

Crew members' mail might be routinely transmitted by satellite link, as well, if communication costs become sufficiently low. Electronic mail transmission is a current reality (Caswell, 1977).

Combat Information Center

As indicated above, it is anticipated that the combat information center of the year 2000 ship could be tied to higher command levels and central computers by high capacity communication links. In combination with the volume of sensor data, high speed processing, and decision aiding which should be available, the speed and effectiveness of decision making will be far greater than in today's ships.

Data from central computers could allow target locations to be shown within a radius far exceeding the range of detectability by the ship's own sensors, according to a varying scale or detail. All detectable targets, with tags, history, and projected tracks, could be displayed much like today's air situation displays. Beyond the detection range, targets known to the central (shorebased) computers could be selectively displayed. Particularly important targets would be displayed to long ranges.

The redundancy of data sources and modes relative to each target and the interactivity of shipboard and shore-based computers could tend to increase the confidence which could be placed in displayed information and would tend to decrease inappropriate decisions, as occurred at Pearl Harbor in 1941.

The close and rapid interaction between the ship's CIC and higher commands could similarly prevent Pueblo-type occurrences which are greatly exacerbated by absence of timely action.

The progress of the Office of Naval Research sponsored decision aiding research is also noted relative to this type of problem (Sinaiko, 1977).

A higher volume of reliable information may therefore be available at the CIC from a ship's own sources and from the communications network. Decision making may, accordingly, be more rapid, based on more data, and aided. In important circumstances, ships' officers should possess the capability for consulting directly with or be directed by higher level commanders (Marshall, 1974).

Navigation and Piloting

The capability for almost full automation of navigation tasks should be almost available by the year 2000. Primary reliance will probably be placed on an on-board inertial system for navigation and determination of position, as evident in current FBM submarines. Position data might also be obtained automatically through comparison of bottom contours with computer-stored charts (Pryor, 1966). Military ships may tend to place less primary reliance on shore beacons or satellites, due to the effectiveness of satellite hunting satellites (Defense, 1977). Given detailed, self-contained navigation by inertial techniques as well as bottom reference, development of fully automatic piloting, in which only origin, destination, and desired time of arrival need be entered, seems a simple step. Weather data from shore stations could be sent to ships, and these data could also be considered by the piloting program.

Collision avoidance represents a necessary adjunct to the advanced autopilot. A system employing interaction between computers aboard converging ships, similar to the aircraft system currently under development, was described by Klass (1976).

The piloting station of the future will probably not appear similar to current design. Controls similar to those currently used in aircraft or automobiles may be employed. Displays may be grouped around the pilot according to frequency and criticality of use--as is evident in current SES design.

Conversations with ship officers have indicated a reluctance to accept an unmanned bridge while under way. However, in open seas, a single man standing watch may be acceptable. If manual piloting is employed, a pilot and single lookout should suffice.

Maintenance

It is anticipated that during the twenty-first century, onboard maintenance activities should include few tasks other than inspection, routine servicing, and replacement of modules. Mechanical equipment, it appears from present trends, will have been replaced by highly reliable, solid-state electronic services. Electronic systems should be extremely compact. Even now, there is a trend towards small modules which perform large task segments. Automatic switchover to available spares may be frequently employed. Crew members may be required to replace failed modules, but there should be less urgency to these tasks. The replacement procedure should be to simply remove and replace lightweight modules specified by automatically printed requests. This capability is already available. Manual or interactive fault isolation should not be required. Maintenance tasks which call for lengthy, difficult, or detailed procedures should be performed by shore or tender parties as is currently the practice in "I Level" maintenance.

Sensors and automatic alarms may be heavily utilized to detect fires, leaks, and out of tolerance conditions. Responses to alarms should be automated to some extent. However, walk through inspections, as described for the propulsion plant, will probably be required on a regular schedule.

Administration

The available computer capability aboard ship should relieve ship's personnel of many routine administrative responsibilities. Tasks such as development of duty rosters could be performed with computer assistance subject to review by responsible crew members. Tasks which are relatively unrelated to the ship's functioning, such as maintenance of pay records, promotions, and the like should continue to be performed at shore bases (Fulton, 1974).

Disciplinary actions, performance evaluations, etc., will probably remain human functions, although these functions could be recorded at computer terminals rather than on paper.

Through changes such as these, shipboard personnel could be relieved of a considerable volume of administrative work. Senior personnel could suffer fewer interruptions of their primary tasks, and fewer administrative clerks might be needed.

Hotel Functions

All hotel functions could be streamlined and simplified for ships launched around the year 2000. The interviews conducted in the course of the present program indicated that: (1) much food service could involve highly palatable preprocessed foods, (2) microwave ovens could additionally speed food preparation tasks, and (3) on large ships, some traditional "home cooking" may be retained because of its effects on morale. Automatic scullery and self-clearning equipment could help to minimize housekeeping requirements in the galley.

Normal uniforms could be "wash and wear," easy care jumpsuits which only require machine washing and drying to be ready for wear. Housekeeping tasks could be performed using methods common today--power vacuum cleaners, and polishers. Manual cleaning of areas could be required, but the design of ships with paneled compartments [illegible] enclosed pipes, cables, etc., would minimize the time and effort to be devoted [illegible] cleaning (Saklem, Castle, & Weiler, 1971).

Personnel Requirements

As the Navy moves toward the twenty-first century, the requirements on crew performance should probably change considerably. Physical strength should become progressively less important as ship components are lightened and labor-saving machinery becomes more prevalent. Crew members should be required to perform less information processing and problem solving. Analytical portions of maintenance activities may be reduced. Derivation of solutions in target tracking may be performed by computer. Evaluation of target signatures, tagging of targets, control of propulsion plant, navigational computations, setting up of communication circuits, routine administrative tasks, and many other tasks could become almost exclusively machine functions. Human functions in the ship of the year 2000 will probably tend to involve primarily higher level decision making, such as mission planning, analysis of observed activities, overseeing automated functions, operating automated machinery, performing scheduled inspections, housekeeping, and participating in training. Crew members' responsibilities are likely to include tasks assigned to several specialties in current practice.

Sizeable blocks of time could be devoted to training in future ships. This training could be related to personal growth and/or ship operation largely related to operations during battle conditions.

Casualty control training exercises should also be common. Manual operations to control fire, flooding, etc., might be reviewed and practiced.

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