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A METHOD FOR PREDICTING MANNING FACTORS IN POST YEAR 2000 SHIPS

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While each of the developed models possesses some advantage, a combination of two or more of the models would probably yield the most useful predictions.

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ABSTRACT

The prediction of required manning in post year 2000 ships represents a complex topic which must consider technological advances, automation trends, and changes in the functions performed by system operators/maintainers. In order to explore whether or not a computer simulation approach possesses potential for providing manning estimates for post year 2000 ships, some characterization of the ships of that era was believed required. To obtain this characterization relevant literature was reviewed and synthesized. Additionally, interview information was acquired from a number of scientists who deal with advanced technologies. Then, four different computer simulation models, which are held to possess potential for achieving the required post year 2000 manning predictions, were outlined and described.

While each of the developed models possesses some advantage, a combination of two or more of the models would probably yield the most useful predictions.

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I. INTRODUCTION

Bacon advised that "Truth emerges more easily from error than from confusion." George Homans described scientific progress and methods in rather direct terms: "Science progresses by some of the damnedest methods." The present study represented an initial exploration of the feasibility of developing methods for reducing confusion relative to the estimation of manning requirements for post year 2000 Navy ships. Such ships will involve even more advanced technologies and automation than we are witnessing today. They will probably perform new functions and demand personnel qualifications and task performances which are vastly different from those which currently exist. Unfortunately, no specific method is available which allows the prediction of the manning requirements for such ships. It is necessary to know, early in the planning stages of such ships, the answers to such questions as:

- How many men are required to man this ship?
- How should the crew be organized and what is the required skill, training, and cross training mix?
- How many men should be assigned to each ship function?
- What is the probable effect of various personnel oriented tradeoffs on system effectiveness?
- How will various social, psychological, human performance, and man/machine interactive factors affect the crew's performance?
- What overall maintenance and operational functions can the crew be expected to perform best? Worst?
- Will the suggested manning meet the functional requirements and, if not, where are changes needed?

The method considered for providing answers to these and similar questions was computer simulation. Computer simulation is defined in various ways. Examples of such definitions are:

> ...a model or representation entirely realized through a mechanical system (Dutton & Starbuck, 1971).
>
> A logical-mathematical representation of a concept, system, or operation programmed for solution on a high-speed computer (Martin, 1968).

> . . . a numerical technique for conducting experiments with certain types of mathematical models which describe the behavior of a complex system on a digital computer over extended periods of time (Naylor, 1971).

Within the computer simulation context, answers were sought to two specific questions:

- Is it reasonable to think that computer simulation methods can provide answers in the areas of interest?
- If yes, how can such a simulation be approached?

Current Status of Computer Simulation

The current status of the stochastic computer simulation technology is such that this approach represents an accepted tool for system effectiveness prediction. This holds whether economic, social, man-machine, or other systems are involved. Standard texts in industrial design (e. g., Forrester) recommend the use of the technique, as do current texts in human factors engineering (e. g., McCormick). For human involved systems, various agencies have come to rely more and more on the use of such models. Examples of the use of prior models by the military include sonar system and aircraft design in the Navy, advanced aircraft design in the Air Force, communications system investigation in the Army, and fire control system design in the Navy. All of these applications include circumstances in which the use of other types of predictive methods are untenable, uneconomical, or impossible. For example, in a modification of a human oriented digital simulation model developed for the Office of Naval Research, the Air Force developed predictions of the effects of radiation on pilot effectiveness in achieving attack goals. .

Nelson, Gay, and Roll (1974) in a program completed for the Defense Advanced Research Projects Agency strongly supported the need for computer simulation models in manpower planning. They stated:

> What is needed is a model or set of models that can predict the relationships between different mixes of inputs and a (maintenance) group's productivity. Computer simulation models of the operations of a military unit are potentially valuable in this regard. (p.22) (parentheses added)
>
> Research should be undertaken to develop models of military units (where appropriate), to validate the models and to apply them to the evaluation of manning standards. (p.23)

Currently Available Simulation Models

In view of the recent history of the development and application of computer simulation models, the question may be asked: "Why hasn't a model been already developed which will achieve the advanced technological objectives suggested here?" At least two possible answers may be given to this question. One possible answer lies in a general reluctance, in the past, to forecast technological change and the impact of such change. Ayres (1969) stated the situation as follows:

> As businessmen, bankers, actuaries, or government officials, we can make quite good aggregate estimates of such things as the future labor force, employment level, demographic distribution, birthrate, annual inflation rate, gross national product, life expectancy, agricultural production, highway death rate, and demand for housing, fuel, electricity, transportation and education....In short, forecasting, both explicit and implicit, is deeply woven into the fabric of twentieth-century Western civilization.
>
> The forecasting of technological as opposed to economic or demographic change is not yet so universally practiced. In part, this logic is due to a belated recognition of the extent of the impact of technological change on society, and in part is due to a rather widespread notion that technological change is inherently unpredictable (p.3)

A second possible answer to the question lies in the inadequacy of current simulation models when one thinks in terms of post year 2000 ships. The reasons for this lack of adequacy rest on the fundamental structure and content of such current simulation models.

- Current behaviorally oriented models rest, on the one hand, on detailed input data customarily derived from task analytic procedures. These task analytic procedures rest, on the other hand, on a somewhat detailed knowledge of the equipment system design, its operational/maintenance procedures and requirements, and the missions the system is to accomplish. Detailed data of these types are not available for the advanced long term systems on which the present work focuses.

- The behavioral variables included in the current simulation models address themselves to current Navy operational/maintenance tasks and methods. There is reason to believe that different tasks, as anticipated for future systems, will rest on behavioral variables that are different from those included in current models.

- The simulation logic of the present models, essentially the serial simulation of subtask or event performance, is not possible for advanced technological prediction.

Overview of Approach

In order to come to grips with the problems of whether or not a computer simulation approach can possess potential for providing reasonable answers to the problems at hand, it seemed necessary to gain some concept relative to the possible characteristics and functions of ships of the future. To this end: (1) available literature relative to advanced automation trends in ships was reviewed and analyzed, and (2) a set of semistructured interviews was held with scientists and engineers concerned with advanced technological research and development in the Navy. The indications of the interviews and of the literature were synthesized to yield a set of insights relative to the character of post year 2000 ships. Chapter II of this report synthesizes the indications of the literature review and analysis, along with results of the interviews, into a panoramic overview of anticipated changes. The review emphasizes automation effects in view of the current trend in this direction. Automation is considered in the broadest possible terms including elimination of human activity from the operational and/or the maintenance links and integration of functions both within and across ship systems. Chapter III presents the conclusions vis-a-vis the feasibility of computer simulation models in the manning predictive technology area, and Chapter IV describes four possible approaches to such modeling. Conclusions and recommendations are summarized in the final chapter.

II. LITERATURE INDICATIONS AND INTERVIEW RESULTS

Fundamentally, the present study is concerned with predicting how the utilization of Navy personnel in the future will necessarily be different from today's practices as a result of changing functions and of technological developments.

At least two factors seem to be responsible for the anticipated change. Both may yield a similar resultant effect. First, the complexity of modern and advanced weapons and the pace of occurrence of events which require a tactical response are such that the time available for collection, integration, and processing of information may be less than that required for human data processing. Hours or even minutes of warning may not be available in the foreseeable future. Second, manual operations aboard ship are costly and such costs may be impractical in the future. According to Gaites (1974), personnel costs now represent 42 per cent of the operating budget and 26 per cent of the total budget of the Navy. He also pointed out that each man in a modern destroyer size ship requires five tons of ship occupying five hundred cubic feet. Construction costs for this amount of structure approximate $25, 000. This structure must then be maintained for the 30 year life of the ship.

Automatic devices present a very attractive alternative to high ship manning. They do not become inattentive on the job, and they are nearly error free. Such devices can perform many tasks more rapidly and accurately than man and do not require feeding, berthing, support of dependents, retirement benefits, and the like.

Kaplan (1966), after an analysis of current enlisted Navy ratings, indicated that the enlisted manpower of a Navy of fixed size could be reduced by 86. 37 per cent under current manning concepts through adoption of a degree of automation which is presently foreseeable. Estimation of officer manpower required in an automated Navy was considered by Kaplan to be more difficult, and was not undertaken.

Automation is clearly one of the most pervasive of the technological trends. Its overall impact on manning will probably be equal to that of any single advance in weaponry, sensing capability, power source, or other technology.

In order to set the nature of the naval ship of the early twenty-first century into its proper perspective as a knowledge backdrop for a model which will predict manning requirements in post year 2000 Navy ships, forecasts , predictions, assessments of current trends, etc. , were obtained from two sources: review of pertinent literature, and interviews with selected scientists and engineers working at high levels within advanced technological development in the Navy.

Literature Review

Many sources were searched to obtain literature which discusses the ship of the twenty-first century. References were found through the Psychological Abstracts and the Government Reports Index. Various journals (e.g., Naval Engineers Journal, U. S. Naval Institute Proceedings, Scientific American, Naval Research Reviews), newspapers, and other popular publications were also searched. Many extremely valuable references were loaned from the personal libraries of persons at the Office of Naval Research and other agencies. A Defense Documentation Center computer search* was also completed. In this computer search, broad and unclassified coverage for the time period 1965 to present was requested relative to:

> automation/integration of equipment systems relative to problems of: (1) reducing manning requirements through automation/integration, (2) predicting manning/personnel requirements for Navy systems in the post 2000 A.D.era, (3) predicting the required characteristics of operators of automated/integrated systems, (4) projecting the required characteristics of equipment in automated/integrated systems, and (5) determining the effects of computerization on personnel requirements.

Interviews

Publications describing possible future ships often present an atomistic point of view which fails to consider the total ship system and other constraints such as economic considerations, societal views, manpower availability, and the conservatism of decision makers themselves. In order to obtain a more rounded portraiture, individual interviews were completed with a number of civilian and uniformed persons occupying positions of responsibility and authority in advanced naval research and development. These persons were asked to discuss, relative to a set of system categories, their expectations of the naval ship of the early twenty-first century, especially with reference to advances in automation. The system categories included were: sonar, fire control, food, navigation and ship control, administration, communication, system maintenance, radar, combat information center, air operations, facilities maintenance, and "other." The interviewees were also asked for a judgment of the degree of automation currently characteristic of the various system categories and their twenty-first century correlates. These judgments were made with reference to the five point categorical scale shown below:

None (fully manual) = 0
Slight = 1
Moderate = 2
High = 3
Fully automated = 4

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*The results of a second Defense Documentation Center search were kindly provided by Dr. David Meister.

Each interviewee was also asked to describe the specific change(s) which he anticipated in each system category.

The predictive ratings of each interviewee are presented in Table 1, along with the corresponding ratings of the interviewees relative to the automation level of each system category at the present. Table 1 also presents the differences between the mean present and future ratings.

Current systems were rated on the average to be at about a "slight" (mean = 0. 98) degree of automation and a gain by the year 2000 to between "moderate" and "high" automation (mean gain = 1. 2) was anticipated. The average percentage of increase in automation relative to the present level of automation was 119 per cent.

In order to assess the extent of agreement among the ratings across interviewees, Pearson product-moment correlation coefficients were calculated among all possible pairs of interviewees. The obtained values are shown in the matrices of Tables 2 and 3. The obtained correlation coefficients indicate a considerable variety of levels of correlation between pairs of raters. While most of the Table 2 and Table 3 values are positive and, in some cases, high, there is also a substantial number of negative correlational values. The overall correlation among rater judgments relative to the degree of automation of present systems was . 36 and the overall agreement correlation coefficient for future systems was . 23. Both of these values are statistically significant below the . 01 level of confidence. These data support a contention that there appears to be some, but not high, agreement among the experts interviewed relative to the present and the anticipated degree of automation of Navy systems.

The reasons for this lack of high agreement among interviewees relative to current systems are not entirely clear. One possible explanation is that the interviewees were asked to make judgments relative to the degree of automation of all system categories--those within their area(s) of expertise as well as categories outside of their area(s) of competence. Quite obviously, judgments in the latter case would be subject to considerable random error. Second, it is also possible that the categorical scoring distorted the data. Use of the lowest (zero) and highest (four) scale categories would not be anticipated for most current system categories. Table 1 supports this conjecture. Accordingly, there is a range restriction which is known to reduce correlation. Finally, the categorical scoring can distort minor differences and make them appear larger than they actually are in the minds of the persons involved.

On the other hand, some degree of disagreement relative to conjectures about post year 2000 systems would be anticipated. Still, the inter-interviewee correlation coefficients for the post year 2000 estimates could suffer from the same distortions mentioned above for the current status correlation coefficients.

Table 1

Interviewee Ratings* of Degree of Automation of Current and Early Twenty-First Century Systems

Interviewee / System	Sonar		Fire Control		Radar		Commun.		Sys. Mnt.		Facil. Maint.		Navig.& Ship Control		Propul.		Air Support		Admin.		CIC		Food			
Time	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	Present	Post 2000	x̄ Present	x̄ Post 2000
1	.67	1.33	—	—	1.00	1.67	0.00	1.00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	1.00	1.00	1.00	2.00	1.00	2.00	1.00	2.00	7.00	2.00	0.00	1.00	0.00	1.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.54	1.27
3	0.00	2.00	1.00	3.00	1.00	3.00	0.00	2.00	0.00	2.00	—	—	1.00	3.00	0.00	2.00	0.00	2.00	1.00	2.00	1.00	3.00	1.00	2.00	0.54	2.36
4	1.00	2.00	2.00	3.00	1.00	3.00	1.00	2.00	0.67	1.33	1.00	2.00	1.00	3.00	1.00	3.00	0.00	1.00	0.00	0.00	1.00	2.00	0.00	3.00	0.80	2.11
5	1.00	1.00	1.00	2.00	1.00	2.00	1.00	2.00	0.00	2.00	0.00	0.00	0.00	1.00	1.00	2.00	1.00	1.00	0.00	1.00	1.00	2.00	—	—	0.64	1.45
6	2.00	3.00	1.00	3.00	2.00	3.00	1.00	2.00	0.00	1.00	0.00	1.00	2.00	3.00	2.33	2.33	0.67	1.33	0.00	1.00	1.00	1.00	0.00	1.00	1.00	1.89
7	2.00	4.00	2.00	4.00	2.33	4.00	2.00	3.00	1.00	2.00	1.00	1.33	3.00	3.67	2.00	4.00	1.00	2.00	1.00	2.00	1.00	3.00	—	—	1.67	2.91
8	1.00	3.00	2.33	3.33	3.00	3.33	2.33	3.33	1.00	3.00	1.33	3.00	2.00	4.00	—	--	2.33	3.33	2.33	3.33	3.00	3.33	2.00	3.00	1.88	3.27
9	2.00	3.00	1.33	2.33	1.00	3.00	1.33	2.33	0.33	3.33	0.33	1.67	1.00	2.33	2.00	4.00	1.00	3.00	0.33	3.33	1.00	3.00	0.00	2.00	0.97	2.78
x̄	1.19	2.26	1.46	2.83	1.48	2.78	1.07	2.22	0.50	2.06	0.52	1.43	1.25	2.50	1.33	2.76	0.86	1.95	0.46	1.58	1.12	2.29	0.50	1.83		
DIFF.	1.07		1.37		1.30		1.15		1.58		0.91		1.25		1.43		1.09		1.12		1.17		1.33			

*In some cases the interviewee wished to depart from the categorical rating. In these cases a + or a ++ was allowed. The single + was scored as one third of a scale unit and a ++ was scored as two thirds of a scale unit.

Table 2

Product Moment Correlations Among Interviewees Relative to Degree of Automation of Current Navy Systems

Interviewee	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
*1**	—	—	—	—	—	—	—	—
2		-.60	.52	.47	.12	.14	-.11	.40
3			.09	-.07	.12	.14	.56	-.27
4				.60	.43	.45	.43	.59
5					.45	.14	.56	.74
6						.82	.35	.72
7							.23	.50
8								.11

**Insufficient data available for correlation*

Table 3

Product Moment Correlations Among Interviewees Relative to Degree of Automation of Post Year 2000 Navy Systems

Interviewee	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
*1**	—	—	—	—	—	—	—	—
2		.18	.60	.29	.31	.14	-.21	-.10
3			.74	.26	.40	.48	.58	-.11
4				.34	.78	.78	.34	-.24
5					.17	.49	-.30	.14
6						.84	-.31	-.33
7							.38	-.39
8								-.62

**Insufficient data available for correlation.*

In terms of estimated current level of automation, the discussed system categories fell quite neatly into two groups. Six system categories were rated as between "none" and "slight" in current degree of automation: system maintenance, facilities maintenance, administration, food, intelligence (mentioned by one interviewee), and air. The current level of automation of sonar, fire control, radar, communications, navigation, propulsion, and CIC were rated between "slight" and "moderate" in current level of automation.

As a group, the more highly automated systems of today were projected to increase slightly more in automation than the currently less automated systems. The higher rated system categories were expected, as a group, to increase 1.25 units, to a point between "moderate" and "high" automation. The less automated system categories were estimated to advance to "moderate" levels of automation and to gain 1.08 rating scale units, as a group. The stated reasons for high or low expectations of advances in automation in each of the system categories involved will be discussed in subsequent portions of this chapter, along with the literature indications relative to each system category.

Sonar

The mean rating of the interviewees for the degree of automation of current sonar systems was 1.19 (between "slight" and "moderate"). This value is approximately at the median of the various system categories considered. Twenty-first century sonar was expected by the interviewees to be automated by slightly more than one rating scale unit (between "moderate" and "high"). Less increase in automation was expected only in the case of facilities maintenance. This thinking parallels that of Crowder (1974), who considered increases in sonar system capability to be unlikely, except in the area of signal processing. According to Crowder:

> Sonar development appears to have realized asymptotic levels....The remaining possible areas of large gain in the sonar field is (sic) sophisticated signal processing.

Similarly, Kaplan (1964a) argued that present sonar tasks are largely heuristic operations. He indicated that such tasks are very difficult to automate and, accordingly, suggested that sonar will be among the last systems to be automated. Siegel and Williams (1974) similarly indicated, for example, that setup of a multifaceted sonar system represents a task which cannot be performed in a deterministic way. Accordingly, novel methods of training sonar supervisors in the use of such systems were suggested in order to provide a new, heuristic style of sonar operation. Prompting of supervisors by computer has already been incorporated in the AN/BQQ-5 system (Siegel & Williams, 1974). Such prompting will probably be used to an increased extent to avoid the adoption of stereotyped system configurations which are less than optimal for specific operational situations.

From the search, detect, and track points of view, increases in signal processing capability would probably lead to increased operator unburdening and increased capability to handle multiple targets. However, classification is fundamentally a heuristic process and, following Kaplan, a large degree of automation and complete operator unburdening relative to classification can probably not be anticipated with confidence.

A further trend is the development of remotely piloted sonar hydrophone units. Crowder (1974) described such units for high speed craft. Sonar personnel will be required to dictate the successive drop point positions for such units on the basis of target behavioral data, oceanographic conditions, and the like. These decisions are likely to be made with computer assistance.

In summary, current sonar was rated by the interviewees at approximately the median of the system categories considered in terms of current level of automation. Some slight increase in level of automation seems indicated, but both the literature and the interviewees seemed to agree that a quantum jump will not occur. New sonar functions may add to the job requirements. Some unburdening may be anticipated relative to the detection and track problem, but full automation relative to the classification problem may not be easily achievable.

Radar

Currently, radar was perceived by the interviewees as the most automated of the discussed system categories (mean value = 1.48; between "slight" and "moderate"). In the early twenty-first century, according to the interviewees, radar will also be relatively high in degree of automation (mean value = 2.78; approaching "high"). The difference between the ratings of post year 2000 radar systems and present systems was 1.3 scale units.

To some degree, the anticipated increases in automation may have been confounded with estimates of increases in capability as a function of nonradar, but radar mimicking, technological advances. For example, Fulton (1974) discussed future systems which will make use of infrared radiation for search and track of airborne targets. The advantages lent by an ability to search and track without making active transmissions are clear.

Availability of these various additional systems for detecting and prosecuting airborne targets will have the disadvantage of bringing sonarlike problems of mode selection to the "radar" operator. Mode selection, at least in the case of sonar, was not believed to be easily automated. Similarly, the classification problem can be partially automated, but full automation does not seem to be anticipated. Substantial automatic search and track capability already exists in radar and a continuation of this trend seems probable. As for sonar, advances in signal processing capability will probably continue, and there is reason to believe that these will result in changes relative to the roll of the radar operator from the search, detect, and track points of view.

Radar maintenance will probably benefit from general advances in the electronic maintenance concepts. Such trends are discussed subsequently under "system maintenance and repair." Similarly, advances in computer capability (also discussed in a subsequent section) will serve to unburden the radar system operator. According to Crowder (1974), radar units will be deployed on RPV's. Use of these RPV's, which will be able to remain floating on station for days, will allow use of active sensors without revealing the position of the mother ship.

In summary, it seems that advances in electronic and electronic related arts could result in some further unburdening of the radar operator/maintainer. Full automation of the radar function, which was perceived by the interviewees to be relatively high on present degree of automation, does not seem to be anticipated either on the basis of the literature or the interview indications. However, a continuation of the relatively high degree of automation of radar functions seems indicated.

Fire Control

Fire control functions were considered by the interview group to be relatively high on automation at present (mean value = 1.46; between "slight" and "moderate"), and fire control received the highest automation rating for the years post 2000 (mean value = 2.83; approaching "high"). This appears to be a highly supportable prediction. Present fire control functions include computation of relative position of own ship and target in fast-time, aiming or programming of weapons, providing aiming information, and actual weapon selection, firing, or launching. All of these functions are sufficiently determined that they may be more rapidly and accurately performed by computer in future systems. We may even see automation of the decision to fire a weapon in certain situations. As a step in this direction, Pettitt (1974) points out that:

> NWP-31, the antiship missile defense doctrine, specifies that commanding officers should delegate firing authority to evaluators during a high threat situation....COs do need to know how to delegate authority to defend their ships in rapidly developing high threat situations....The necessity to compress drastically the time required for recognition of a threat through its evaluation, consideration of weapons capabilities, weapons assignment and analysis of weapon performance, until final kill, makes it evident that bold steps must be taken. Henceforth, reactions will be measured in seconds rather than minutes. Decisions, as well as evaluations, will undoubtedly be required from the officer "on scene" at the time the threat evolved, since time will no longer permit the old "detect-evaluate-disseminate" routines established in World War II.

As pointed out by one interviewee, in the eventual case of weapons which arrive at the speed of light, even speed of light analysis and reaction may not be fast enough. In fire control systems under development, such as the MK 113 MOD 10 submarine fire control system, target motion analysis is performed through an interactive effort involving the operator and the system (Naval Ordnance Systems Command, 1971, 1972). For future surface systems, it seems that human input will not be needed for these analyses.

There also seems to be a trend toward the integration of sonar and fire control functions on underwater crafts and possibly sonar-radar-fire control integration on advanced surface ships. The Naval Underwater Systems Center has already sponsored a series of studies into the feasibility of such integration (Williams & Siegel, 1972; Siegel & Williams, 1972; Siegel & Williams, 1973) from the man-machine integration point of view.

Consider the MK 113 MOD 10 fire control system in which there is a distribution of responsibility between sonar and fire control. Information of value to the sonar supervisor for the tactical utilization of thermal layers to manage detectability and detection capability is received from the fire control system operators. Critical delays in changes of sonar configuration may result from the necessary passing of information from fire control or command personnel to the sonar supervisor. Additionally, Siegel and Williams (1972a) demonstrated that periods of high activity of submarine sonar and fire control operators may occur at intermeshing periods of time. This intermeshing indicates a level of inefficiency in information availability and a need for function consolidation.

Following the same logic, functional consolidation might be anticipated in certain surface ship sonar-radar-fire control-combat information center functions. At least on the general level, fire control seems to be dependent on complex data derived from many sources. The data must be manipulated in sophisticated manners and action taken on the basis of the results of these manipulations. All of this must be quickly and accurately performed. Accordingly, fire control seems to represent a prime candidate for automation/integration. This thinking was probably reflected by the interviewees when they rated fire control as one of the systems in which automation will probably be greatest.

Communication

The interviewees rated current communication systems as "slight" in degree of automation. In the early twenty-first century, they indicated that the automation level of systems in the communications category would be slightly above "moderate." Advances were foreseen in transmission rate and laser communications systems, with their high channel capacity, were thought to contribute to this increase. Lasers would also provide a means for "narrowcasting" (a narrow laser beam as opposed to the broad beam of even the best radio broadcasting) with a resulting difficulty of hostile interception. However, such a system is strictly line of sight and would be subject to scattering by any nonideal weather conditions.

Automatic encryption and deencryption were considered to be highly possible. The interviewees also foresaw automatic setup and warmup of communication gear. To these, the possiblity of automatic channel monitoring, message recording, and message processing can be added.

Closer interaction with higher command levels will probably become a reality. Marshall (1974) described the Secure Imagery Transmission System (SITS), which has demonstrated the feasibility and practicality of transmitting combined visual and voice information in a real-time secure mode. Installation of this system in the fleet awaits only the availability of sufficient communication satellites, in Marshall's opinion. Data links such as those of the FLTSATCOM system, which link shipboard and land-based computers, are also to be expected.

The interviewees seemed to think that the volume of communication expected in future periods will make automatic operation of communication systems mandatory. Such a trend, it was indicated, will necessitate the adoption of formatted, addressed messages and systems which will respond selectively to message heading information. The General Address Reading Device (GARD) reported by Wilcox (1975) seems to possess automation features which can be anticipated to be commonplace in future systems. Such systems would allow only messages directed to a given ship to be copied by its communication systems. The masses of nonpertinent material now processed by communications personnel would be ignored by the system.

Wilcox (1975) and Cram (1967) also described a fully automatic, redundant processing, Message Processing and Distribution System (MPDS). The MPDS automatically logs traffic and prepares and stores microfilm copies of each message. It then prints the message on a remote terminal at the appropriate duty station.

Another advanced message transmittal system, applicable to submerged submarines, was described by Kruger (1972). Kruger described the SANGUINE system which relies on extremely low frequencies for transmission of only high priority operational messages. Within such a system, it seems reasonable to anticipate automatic channel monitoring and immediate presentation of messages at the command level.

In summary, the trend seems to indicate that manual operations in twenty-first century communication systems will be largely limited to channel and mode selection and message input. Quite obviously, such automatic processing of messages allows considerable reduction in manning and increases the reliability of transmission.

System Maintenance and Repair

Maintenance and repair of systems (facilities maintenance is treated separately) in current ships is almost completely manual, in the opinion of the interviewed persons. In the next 30 years, however, advances in system maintenance will be greater than those in any other discussed system category, as measured by change in rating. Specifically, according to the interviewees, early twenty-first century system maintenance will be "moderate" in degree of automation, and the potential exists for more basic changes in philosophy, procedures, etc., than any other class of shipboard activity. These changes may or may not be classed as automation, but they will strongly influence the nature and amount of system maintenance activity performed by ship crew members. Many of the anticipated maintenance procedures rely on the availability of digital computers for controling system check, system analysis, and fault location functions. Crowder et al. (1974) estimated that by the year 2000 "The large computers of today will be about the size and cost of today's hand calculators." Accordingly, one can anticipate extensive use of digital computational equipment for the purposes indicated, and one may optimistically foresee automatic self-tests performed on a scheduled basis.

Additionally, some interviewees anticipated a very high level of reliability for miniaturized, highly integrated circuitry in the foreseeable future. High reliability would decrease maintenance requirements.

Loy et al. (1975) presented curves showing the anticipated use of automatic test equipment (ATE) and built in test equipment (BITE) as a function of the advent of microelectronics. They also presented a prediction of the use of ATE and BITE from 1970 onward. The Loy et al. curves are presented in Figure 1. Quite obviously, such a trend would have direct effects on qualitative and quantitative manning requirements.

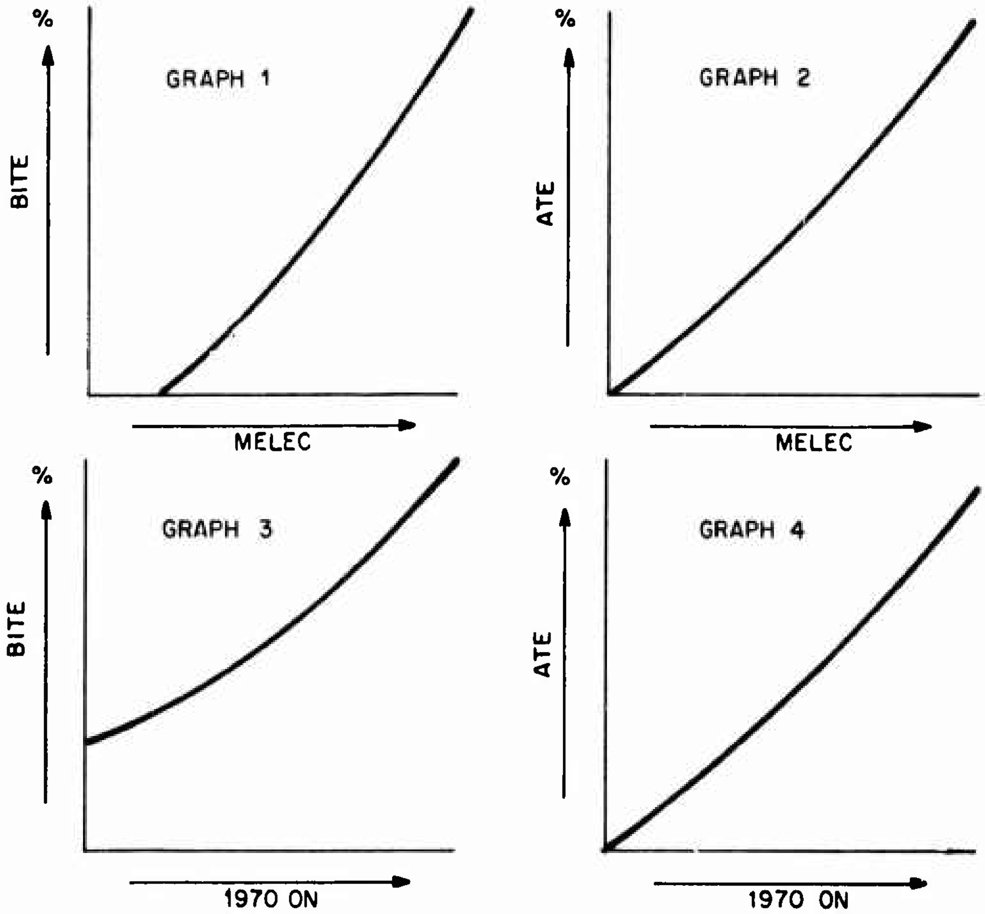


Figure 1. Effects of microelectronics. (From Loy et al.,1975)

Although the Loy et al. work was performed with reference to fire control system maintenance, there is little reason to believe that the trend does not apply to other advanced systems.

Computer control could also be employed, the interviewees stated, to switch in a module for a failed module and to type out a message indicating what module has failed.

Fulton (1974) supported these contentions. He indicated that the technology required for self-testing, self-diagnosing, and "self-healing" circuitry is already available, and Steckman (1973) described an approach, based on today's technology, which allows test functions to be provided through software routines.

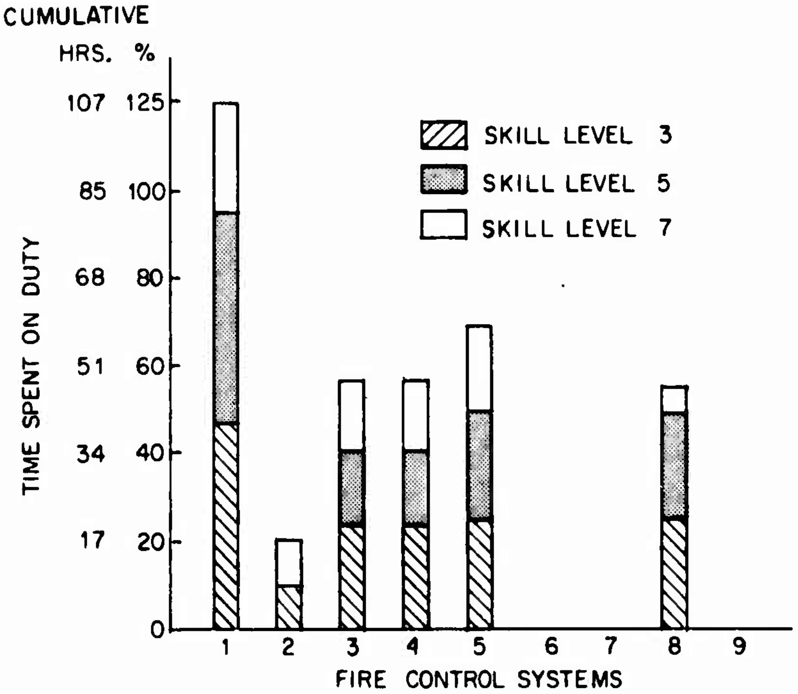
Kaplan (1966b) foresaw major developments in microcircuitry. He anticipated that these advances will "automate electronic maintenance as we know it out of existence" (p. 10). He expected that future microelectronic systems will be very compact, light in weight, operate at very low power levels, produce very little heat, and require very few components and connections, as compared with current systems. These systems, according to Kaplan, will be built at very low cost and will be highly reliable and maintainable. He contended that ships could carry highly redundant systems, which are broadly distributed onboard, and that maintenance could be done ashore by poorly skilled individuals who are provided with flow charts and large diagnostic computers. "The skills and knowledges now associated with electronic maintenance will no longer be required' (Kaplan, 1966b, p. 9).

The trend toward superminiaturization will, in itself, aid in simplification of electronic maintenance. Present day discussions (e.g., ITT, 1973) of diagnostic systems commonly mention isolation of faults to the level of the smallest replaceable unit. In the twenty-first century, powerful large scale computers are anticipated which can be held in the palm of the hand and production cost is anticipated to be minimal (Toffler, 1971).

The maintenance requirements for mechanical and electromechanical components were also considered by the interviewees. The consensus seemed to be that these requirements will also be considerably lowered by the year 2000. Interviewees mentioned the development of superior materials, bearings, and lubricants which will reduce the amount of maintenance needed for these types of equipment. It was also suggested that advances in knowledge of materials will allow more accurate prediction of the useful life of parts. This would increase the effectiveness of preventive maintenance programs and reduce the need for onboard maintenance.

It was indicated that fully automatic repair by mechanical manipulators, although conceivable, is not highly probable for the time period under consideration. The reasoning seemed to be that the cost of building and installing such devices to perform card or module replacement is not likely to compare favorably with costs associated with provision for automatic switching to redundant modules.

Overall, it seems that the quantity of system maintenance required aboard ship will tend to decrease as we approach the twenty-first century, and the necessary maintenance skill level requirements, as we know them today, are anticipated to decrease correspondingly. However, we note that this anticipated trend is not substantiated by Air Force data. Loy et al. (1975) summarized the time spent on duty for various skill levels on aircraft which have entered the Air Force inventory since 1959. All the data relate to fire control system flight line checks. The data of Loy et al. are presented as Figure 2, and fail to indicate a qualitative difference after entry of the F-4C aircraft into the Air Force arsenal.



Gp.	Equipment	Mo.**– Yr.	X	Y
A	F-106A/B	7-59	1	124.7
A	F-105D	5-60	2	20.0
A	F-4C	5-63	3	56.0
A	F-4D	12-65	4	56.0
A	F-4E	10-67	5	68.1
B	F-111A	10-67	6	
B	FB-111A	7-68	7	
B	A-7D	12-68	8	55.1
B	F-15		9	

**Date Entered AF Inventory

Figure 2. Time spent as a function of skill level for AF systems introduced between 1959 and 1968

Facilities Maintenance and Repair

According to the interview data, facilities maintenance is presently very low in automation and will remain relatively low in automation in the twenty-first century. Some persons anticipated automatic fabrication, welding, and inspection of structures, but these are primarily shipyard innovations.

However, some interviewees indicated that changes in onboard facilities maintenance requirements may result in the near extinction of such duties. Fulton (1974) and Kaplan (1966b) agreed with the majority of the interviewed persons on this premise. Advances in multilayer paints were said to be expected to preclude the need for extensive corrosion preventive maintenance. Future ships were expected by these persons to be quite well sealed environmentally, and Fulton implied that good design of remaining deck hardware could do away with nearly all remaining deck maintenance tasks. Within two years, two demonstration type destroyers will be in service which will have no facilities maintenance functions performed by the crew (Gaites, 1974). These functions will be performed during two to three day layovers exclusively.

Little interest was found in the retention of "character-building" facilities maintenance tasks, in either the literature reviewed or the interview data.

Navigation and Ship Control

According to the interviewees, navigation and ship control represent a system category which is relatively modest in automation at the present (mean rating = 1.25; somewhat higher than "slight"). In ships of 30 years in the future, the degree of automation in this area was expected to be exceeded only by the radar and fire control systems. Both the literature (Gaites, 1974; Price, 1974; COMDESDEVGRU, 1973; etc.) and the interviewees indicated the Navy to be very interested in reduced shipboard navigation and ship control manning. The interviewees agreed that automatic navigation steering devices will guide naval ships from point to point and that inertial guidance and satellite data will provide position information. The result would be reduced manning because of the abolition of lookouts, helmsmen, and similar personnel.

Persons inverviewed expected that manual control would be retained during docking, battle conditions, and close maneuvering. They seemed to think that taking fixes by sextant would continue, although navigation would normally be an automatic function. Feldman, Seidlemann, and Barton (1974) discussed the design of remotely controlled automated sextants which may be used in any weather and at any time of the day. According to these authors, current advances in low light level TV, night vision telescopes, and microcircuitry make such devices feasible. Feldman, Seidlemann, and Barton also pointed out that celestial navigation is a necessary backup to inertial and radio navigation systems, in order to correct errors, as well as to protect against failures.

Kaplan (1966a, b) indicated that automatic navigation is already operational (SINS) and is feasible based on LORAN, SHORAN, sonar, and radar.

Such current navigational aids as radio beacons, OMEGA, DECCA, sonar beacons, and comparison of accurate echo soundings with precise depth charts could also provide input to automatic navigation equipments (Pryor, 1966). Wendt (1970) pointed out that collision avoidance will be a severe problem in unconventional ships with cruising speeds of 50 to 100 knots. Collision avoidance problems are currently under investigation by the Maritime Commission (1975) and following their lead, it seems that high speed transit collision problems will be resolvable in the era under consideration. Collision avoidance functions may be performed by radar/fire control systems. Collission avoidance systems are included in the integrated bridge concept developed for the DE-1052 class ship (Moe & Rogers, 1974; Puckett, Gowen, & Moe, 1975).

Other trends relative to ship control integration are found in the work of the Canadian Navy (Lewis, de la Riviere, & Logan, 1966), which has tested a system in which control is exercised over the engine and rudder from novel controls installed on a projecting portion of the bridge. Maneuvering precision was said to be superior using this system, as compared with the traditional system. Other purported advantages of this integrated system were that misinterpretation of commands was avoided and the speed of implementation of commands was greater. More importantly, from the point of view of the present analysis, the integrated bridge eliminated certain traditional bridge and engine room personnel requirements because lookouts were unnecessary, the captain controlled the helm directly, and there was no need for an engineroom telegraph.

Other analyses of automated bridge functions and modifications of personnel responsibilities have been sponsored by the U. S. Navy. COMDESDEVGRU (1973) analyzed the effects of the availability of various automatic devices on required bridge manning of destroyers. They found that an automatic bell logger relieved the need for a lee helmsman. A fog signal timer, autopilot, and a radio message recorder were found to each save one manned station on particular watches. Moe and Rogers (1974) presented a new integrated bridge design for the DE-1052 class destroyer. By effective design and addition of a degree of automation, they achieved a reduction of normal bridge manning level from 14 to 3. They also maintained that there is no expected loss of efficiency in the automated/integrated design.

Projecting the current trend, it appears as if there will be a high automation level in ship control and navigation functions in post year 2000 ships. The number of personnel assigned to these functions will probably be considerably lower as compared with current practice, and the responsibilities of each man will probably be unlike those of current bridge personnel.

Propulsion

The problem of supplying motive power to future naval vessels seems to have taken on new dimensions in recent years. The persons inverviewed reflected this trend. The interview derived data indicated that the group expected the year 2000 level of plant automation to approach "high" and to be exceeded only by the radar and fire control categories. One individual pointed out that optimization of speed, fuel consumption, etc., could be more effectively attained under automatic control.

Nuclear propulsion will not be dominant in ships of the twenty-first century (Crowder et al., 1974). Large and small ships might benefit from the low frequency of refueling, constant ship draft, etc., which would be afforded by nuclear propulsion systems. However, Crowder pointed out that nuclear power plants are far heavier than conventional plants in sizes needed for small and medium-sized ships. This drawback, along with life cycle costs, make nuclear power a desirable choice only for very large or very specialized ships, according to Crowder.

Manne (1975) expressed concern over the realism of assuming that power plants of current types will be usable in the twenty-first century, especially in view of the present fuel crisis. Manne's analysis suggested that, assuming necessary research and development activities, new sources of energy for nonstationary plants will become available. As petroleum reserves fall, he anticipated transition, first, to coal based synthetic fuels, as an interim measure, and then to hydrogen. Manne further stated his expectation that synthetic fuels will be used on a large scale in the 1990's, and that transfer to hydrogen power will begin shortly after the year 2000.

While power sources may change, the literature reviewed provided little which suggested that the twenty-first century navy will rely on other than turbine and piston engines of reasonably traditional form. Both Murphy (1970) and Crowder (1974) anticipated propulsion plants as hybrids of various combinations of steam (nuclear or nonnuclear), diesel, and gas turbine. Final propeller drive was anticipated to be gear or electric. Superconducting propulsion machinery is an attractive possibility, according to Edelsack (1975). If problems of high amperage requirement and brush materials can be overcome, he expects that superconducting motors will bring the flexibility and simplicity of d. c. electric drive to ships. Superconducting engines should allow higher shaft horsepower than is allowed by the current electric motor technology, and significant reductions in physical plant weight and volume may be expected. Control over these engines can be projected to be fully, or near fully, automatic. Near full automation of propulsion systems is an operational fact today in certain merchant marine applications. Current supertankers possess completely unmanned steam propulsion plants (Gaites, 1974), and a Russian ship has demonstrated practical automatic restarting of engines (Tiknomirov, 1972). In a similar vein, Rasmussen (1968) argued that reaction to breakdown must be automatic in order to minimize damage. He also noted that under normal conditions, an engineman has very little to do.

From the point of view of manning reduction due to automation, Hauschilst and Ward (1973) pointed out that, due to reduced manning, automated machinery control can reduce initial and life cycle ship costs. For example, at least nine operating engineering personnel could be eliminated from a single screw gas turbine plant by use of computer control. The projected cost savings include the cost of providing berthing and hotel costs, as well as the various personnel costs. Hauschilst and Ward also suggested that such decreases in manning requirements could result in a reduction in ship size. They did not anticipate a completely unmanned plant in naval ships, even in the long term future, and they indicated that a knowledgeable watch stander will be on hand to take control by computer override instructions or remote control. This "Engineer of the Watch" will necessarily be entirely competent to run the plant himself. Seelinger and Bullock (1966) agreed that all engineroom watch personnel will not be eliminated in naval ships because the costs of that degree of automation are too great.

Some trend towards engine control integration is seen in the new DD 963 (Spruance class) destroyer (Litton, 1973). In this ship, turbine control is almost completely accomplished by one man seated at an integrated console. This trend seems likely to continue with a resultant decreased manning requirement.

Air Support

The interview data indicated that the ship functions in the air category (e. g., launch, recovery, control) to be currently at a "slight" to "moderate" level of automation. They anticipated this level to increase to between "moderate" and "high" in future ships. Ship involvement with air vehicles depends on military doctrine relative to aircraft. Air warfare of some type seems logically to be involved in post year 2000 battle.

There seemed to be a number of trends in the literature which indicated increased and modified air operations. However, little was found relative to automation of ship functions associated with such operations. Landing and taking off from a DE-1040 or DE-1052 class ship should be possible with current helicopters up to Sea State 6 (Kolwey & Coumatos, 1975). Aircraft carriers are likely to be smaller (Finney, 1975; Levine, 1975), and are likely to employ VTOL aircraft. Design studies for such an aircraft/ship systems have been performed (Kusewitt, 1972). As stated above, the literature indicated little in terms of automating the ship functions associated with such aircraft, although it seems that the potential for manning reductions in these areas could be considerable. The advent of remote piloted vehicles (RPV's) for sonar, reconnaissance, and other use (Crowder, 1974) will add functions and manning requirements not currently involved. The task of controlling these units will be rather unlike any current naval tasks. Control of these RPV's will be computer aided; they will not be flown via joystick, as are today's radio controlled model aircraft. Accordingly, their control should be less taxing. However, it appears relatively unlikely that deck operations concerned with the launch and the recovery of these RPV's will be automated. This interpretation was supported by some of the interviewees who said that they expect advances to be made in automation of piloting tasks, but there were no references made to changes in tasks of ship crew members.

To summarize, there was little found in the literature which would suggest a large trend toward automating the manual deck work concerned with air operations. Accordingly, manning increases might be anticipated in this area.

Administration

The interviewees judged the degree of automation of present administrative tasks to be very low for present ships (mean = 0. 45; between "none" and "slight"). As a group, they rated the year 2000 level of automation in this category at 1. 6, midway between "slight" and "moderate. "

Certainly, the technology is and will be such as to allow automation of routine administrative functions by the year 2000. Record keeping, payroll processing, inventory management, preparation of duty rosters, etc., could all be automated, and Fulton (1974) stated that he expects that 72 per cent of current administrative functions will be transferred to tenders or shore based organizations or automated by the 1980's.

Automatic logging of engineroom readings and bridge events is already being tested (Moe & Rogers, 1974). The Coast Guard has successfully transferred the task of maintaining damage control books on one class of cutter to a computerized process (Natemeier & Kraine, 1974). This change has: (1) yielded more accurate and legible documents, (2) released a considerable volume of storage space at Coast Guard Headquarters, and (3) relieved ship crews of a very unpleasant and time consuming task.

It would seem unlikely that a maximal level of automation of administrative functions will be implemented. Many administrative tasks, such as duty roster preparation, are primarily involved with people. Maximal automation of these tasks would seem to "dehumanize" a shipboard environment and might well lead toward undesirable changes in crew morale. Automation of many administrative tasks is to be expected by the year 2000, but we should expect that a degree of human review or supervision of these processes will be retained.

Combat Information Center

Interviewed persons agreed with literature projections that Combat Information Center (CIC) personnel will receive considerable aid and prompting in their information handling tasks, but that actual (firing) decision making will remain a human function. The interviewees, as a group, rated the year 2000 level of CIC automation at 2.29 (between "moderate" and "high"). This level is almost identical to the rating for the sonar and the communications categories, in which man may similarly be aided, but not replaced. The mean present automation level of CIC systems for the interviewee group was 1.12 (between "slight' and "moderate").

Increases were predicted to occur in the volume of information to be processed and in the speed requirements for processing this information. To achieve the speed/volume information processing requirements, automation was seen as a solution. Also, novel situational displays, such as that described by Fulton (1974), were projected. Fulton described displays to portray radar and sonar contacts on a single monitor.

CIC functions were probably not projected to receive full automation for several reasons. The need to retain a creative style of tactical decision making seems to preclude full automation (Kaplan, 1966). Also, according to Phillips (1970), computers cannot form decisions based on incomplete, ambiguous, or inconsistent data. The computer has no judgment, and programming of a function analogous to human judgment is not foreseeable. Problems also were said to exist relative to an unwillingness to delegate critical military decisions to computing machinery. Full certification of complex software was said to be a very critical problem, as demonstrated by the BMEWS alert triggered by the rising of the moon, and the failure of the SKY-SHIELD system during a planned exercise (Boehm & Haile, 1972).

Pettitt (1974) also pointed out that the requirement for 24-hour quick-reaction capability will call for a new type of CIC officer. According to Pettitt, the Tactical Action Officer will: (1) have complete command of the ship during his watch, (2) be heavily trained in rapid, effective processing of large quantities of information, and (3) have full authority to act on the available data. He will be highly skilled in interactive, computer aided problem solving. Newmann (1966) demonstrated that human information processing capability is vastly aided by such interactive processing. Boehm and Haile (1972) predicted that direct voice data input to computers will be available in the 1980's. The feasibility of biocybernetic communication, direct communication between brain and computer, has been at least partially demonstrated. Pinneo, Hall, and Wolf (1973) were able to program a computer to identify a limited variety of nonvocalized words through changes in electrical potential of facial muscles. The median estimate of RAND Corp. scientists was that useful biocybernetic communication will be possible by the year 2020 (Toffler, 1970).

Advances in communications, such as those previously outlined, will allow close interaction between on-scene commanders and remote staff personnel. Marshall (1974) foresaw a capability for Pentagon offficials to oversee immediately operations at any point on the globe. Necessary high channel capacity, secure audio, video, and data links will certainly be available by the year 2000 (Marshall, 1974). These links may be expected to be utilized fully on rare occasions.

All of this seems to suggest some trend towards automation of CIC functions. But, considering volume and requirements increases, the effects on manning may be qualitative rather than quantitative.

Food

Food handling and management were rated by the interviewees between "none" and "low" in automation at present, and the group anticipated that the level will rise to almost "moderate" in the early post year 2000 era. Some interviewees indicated that while the preparation of crew meals and allocated tasks have a great potential for automation, this potential may be deliberately neglected, in order to retain crew morale. The "home cooking" aspect of food preparation seemed important to these persons. Interviewees described "Autochef, " a computer driven meal preparer. In this system, a person would request the foods and portion size desired for a meal by push buttons. Food stored by advanced methods such as freeze drying or irradiation would be drawn, reconstituted, cooked by microwave, and served under computer control. One interviewee suggested that the "Autochef" might maintain a record of the foods consumed by each crew member and might present to each person only choices consistent with the maintenance of a balanced diet. No one would be permitted to eat exclusively potato chips and ice cream for extended periods.

Especially on large ships, the more conservative interviewees indicated that a more traditional system for the preparation and serving of foods would be employed because of the previously mentioned perceived need to retain the psychological benefits of "home cooking" and a standard meal time. However, microwave cooking and labor saving devices such as peelers, trimmers, and choppers, are now available and were anticipated to remain commonplace. A single machine which would remove and dispose of garbage, clean and sort utensils, tableware, trays, etc., and return them to storage areas has already been described by the FMC Corp. (FMC Corp., 1963a, 1963b).

The futuristic idea of providing all required nutrients in pill form was not held to be highly likely. So-called "elemental" foods, reconstitutable powdered mixtures of the amino acids, vitamins, etc., necessary for proper nutrition, were rejected by the astronauts (Doane, 1975) because they were held to be unpalatable.

Overall Trends

What then does the interview derived information of the present study and the literature reviewed tell us about the possible nature of Navy ships in the early post year 2000 era?

There were a number of trends indicated relative to information processing. These trends were particularly evidenced in such areas as sonar, radar, CIC, and communications. It seems that data processing can be heavily automated in these areas and the performance of deterministic information processing by humans will be seldomly relied on.

Maintenance was anticipated to change both in nature and in time requirements over the foreseeable future. The information sources indicated that from the electronic equipment maintenance point of view, fault location will be highly automated. This, along with increases in reliability, was anticipated to decrease manning requirements in the long term. From the facilities maintenance point of view, advances in materials, sealants, and coatings were anticipated to reduce requirements for much of the hull, rigging, and associated maintenance which currently takes place.

Integration across various ships systems was also anticipated. Examples are integration of sonar and fire control functions or integration of fire control and radar. Within current systems, integration/automation was also evidenced for individual ship stations. An example here is the integrated bridge manning concept.

While little modification of traditional propulsion system concepts was anticipated for the time period under construction, major changes towards automation of the monitoring and the control functions were anticipated. Considerable progress in this direction has already been evidenced in the DD 963 (Spruance Class) destroyer.

There was also some indication that new manning requirements, not found on current ships, will evolve. Examples of the new functions are control of RPV's and CIC activity.

Considerable change in administration seemed indicated. Most of the routine record keeping was indicated as being delegated to digital computers. This would yield additional personnel and space savings along with considerable dollar savings.

These and associated changes could induce a decided change in the number and nature of officer and enlisted billets. Kaplan (1966) discussed this trend and indicated that persons filling billets in ships of the future will need to be innovative decision makers who can occupy fairly general billets.

However, a requirement will remain for manual performance of many physical tasks. Tasks related to aircraft, such as fueling, parking, tying down, etc., will remain manual jobs, whether the particular aircraft is piloted or not. Loading of weapons, docking, anchoring, etc., are also expected to remain manual tasks. It does not seem likely that it will be economically feasible to automate all of the tasks required in these classes of activities.

As indicated by Saklem, Castle, and Weiler (1971), freeing the crew from many of the tedious aspects of day-to-day shipboard activity may not be without associated morale problems associated with boredom. Thus, these authors advocated various habitability design features to promote a sense of well being and comfort aboard ship.

Of course, there may be many reasons for automation. Even apparently simple decisions of whether or not to automate may be elective in some cases and mandatory in other cases. For example, replacement of men in performance of simple functions may depend on the operational priorities and the resources available. Consider an automatic food service. On a supply ship, the decision to introduce this automation may be elective. On a very complex, specialized vessel, where space is at a premium, the decision to automate could be mandated by the simple fact that the space required for human performance of this task, as well as space for the quarters of food preparation personnel and the space required for their support, cannot be justified.

Automation of complex, tedious jobs which are presently performed by humans might generally be expected to proceed in an evolutionary manner. In some cases, it may not be possible to produce an automatic system to replace the human links in a cognitive/deductive system, but automation of other human functions may be possible.

It is to be expected that for a vessel to survive in a hostile twenty-first century environment there will be need for systems to make conceptually simple decisions with extreme rapidity. An example would be a system to detect the presence of forged radar echoes which are actually being directly transmitted by a hostile force. The evaluation of apparent radar echoes would be made by computer analysis, perhaps with a direct link between the pulse analysis system and the radar transmitters and receivers. It should be noted that such systems would not contain a man in the operational loop, but they could very possibly require very highly trained personnel to exercise them and to check their performances.

Finally, we note that the projections of the interviewee group (on the average) were more conservative than the literature indications. Less change and slower change was anticipated by the scientists interviewed than by the various system proponents and change advocates who write for the publications reviewed. The reason(s) for this disparity is (are) not entirely clear. It may be that the scientists with deeper perspectives are more apt to perceive the problems associated with automation. Or, they may be more familiar with scientific manpower shortages, budgetary limitations, and the like which will tend to limit the speed and extent of change. Nonetheless, those who anticipate vast change in the relatively near future might review their thinking against the data backdrop provided by the interviewees included in the present study.

III. DIGITAL SIMULATION OF AUTOMATION EFFECTS

The prior chapter attempted to place into some perspective current trends in Navy system automation and to extrapolate these trends into the early post year 2000 time frame. The analysis also possesses a number of implications relative to any stochastic computer simulation model which hopes to forecast manpower requirements for ships of the era involved. Chapter III first attempts to weigh certain of the indications of Chapter II relative to a stochastic simulation model which will project manning requirements for Navy ships in the post year 2000 era. Then, certain contraindicative considerations are presented. Finally, the positive and the negative considerations are reconciled into a recommendation favoring the development of such a model for the use under consideration.

Automation Implications

The Chapter II discussion yielded a number of considerations which serve to characterize the requirements for a stochastic model built to predict the manning of post year 2000 ships.

First, while any such model must consider the trend toward automation/integration of various ship systems, in view of the noted conservatism of Navy planners and in view of other constraints, it seems that such a model should moderate the state of the art/science extrapolation in terms of what can be with some conservatism relative to what it seems realistic to anticipate. Second, such a model cannot be a discrete event simulator. While the general character of the crew tasks to be performed on ships of the period under consideration can be stated, the elemental and specific equipment related details of task performance are not now available. Third, consideration must be given to the trend towards operator unloading and system integration. Accordingly, although equipment systems may become more sophisticated to meet advanced requirements, it does not follow that the increased sophistication will mean that more men or even better trained men will be required. Fourth, such a model must be comprehensive enough to accommodate a wide range of technological change across a wide variety of system categories. Unfortunately, as one builds comprehensiveness into a model, he also tends to lose validity. Fifth, such a model should provide as output alternate sets of manning mixes. It does not seem that, when the total ship system goals are relatively unspecified, a one "best" type of manning mix should be prescribed. It would be better to provide the planner with a mix relative to each of the various possible goals of an anticipated system. Sixth, the model should be flexible enough to allow simulation of either individual subsystems or the total ship system. This flexibility seems required because advances may be implemented on a piece meal basis, e. g., a sonar advance may be implemented without a corresponding advance in fire control.

Applicability of Digital Simulation

Certainly, digital simulation models can be built which possess most, if not all, of the characteristics described above. Such models have been built in the past and the methods for achieving such simulations are well within the state of the art. Accordingly, this analysis supports contentions favoring the potential of stochastic simulation models for manning prediction. However, there are a number of other considerations which must be held in mind relative to the total potential of digital simulation models for the purpose under consideration.

Other Considerations

Note, first, that the characteristics described above say little about the validity and the accuracy of the forecasts of the model. While it seems reasonable to expect that a model which possesses the attributes described above will not be entirely unreasonable, it willnot be possible to verify its predictive validity in the usual sense of the word.

Models are not psychometric tests, and some disagreement exists as to how much and what kind (construct, content, concurrent, or predictive) of validity a simulation model must show. It may, in fact, be best to judge a model on the basis of utility rather than on the basis of validity. Nevertheless, the validity concept must be included in any discussion of a model which is under consideration for use as a tool for providing the decision maker with information which will help him to reach the required decisions.

Some modelists have evidently held the point of view that predictive validation is not necessary for a model. For example, a recent volume by Charnes, Cooper, and Niehouse (1972) presents a number of sophisticated civilian manpower planning models. Yet, there is no mention, within the volume of validational efforts relative to any of the models presented. Similarly, most econometric models remain unvalidated. Others have argued that construct validity represents a reasonable approach to model validation. However, to rest the total argument supporting the validity of a model on construct validational contentions seems to be, at best, a "cop out." If the purpose of the model under consideration is to predict the required manning of post year 2000 ships, then the predictive validity of the model remains the item of interest.

Blanchard (1972) recently also stressed the importance of predictive validation in the mind of the model user. He interviewed a number of users of behaviorally based models and, as a result, noted that:

> One of the basic problems noted was that the models developed in the past have not been carried to final, refined state or have they been subjected to vigorous validation studies. (p.36)

and Levy (1969) contended:

> ...Since quantitative prediction seems to be the basic purpose of applied models, predictive validity would seem to be the most important consideration. (p. 3-9)

It is possible, however, that the model under consideration could be validated by using historic data. For example, data from automated merchant ships might be employed to determine whether or not a developed model matches the known manning for the automated condition.

Related to the problem of model validity is the consideration of the accuracy of the predictions. Linus Pauling described his use of the word "stochastic" in the April 1955 American Scientist. According to Pauling, the word is derived from a Greek stem which, in the original, meant "good at hitting a target or at guessing." Quite obviously, a model's predictions should be something more than a guess. Skinner in a similar vein noted that with any predictive model, one must be careful in interpreting the output. He said that it is important to differentiate between "currently probable" and "eventually certain." Quite obviously, the closer the output of the model to the "eventually certain" end of the continuum, the greater is the value of the model's predictions. Yet, a model which targets its prediction 25 or more years into the future is dealing with information which is more in the "currently probable" class than in the "eventually certain" class.

Simulation fidelity is also a matter of interest. Bacon admonished, "Study nature, not books." A stochastic digital simulation model is neither nature nor a book. To the extent that it incorporates nature, a model can be held to possess face validity. This incorporation applies both to the variables included in the simulation and to their interaction within the model. A model which hopes to simulate the ship of the post year 2000 era will, at best, only partially consider all of nature. The totality of nature is just not known. To this extent, a model which aims to predict 25 years into the future will suffer.

Even if one is interested in building a model with a less ambitious look into the future, he will find little to guide him relative to how many and which variables to include. And, no model can incorporate all aspects of the nature it mimics. This is a nontrivial consideration from the point of view of acceptance of the model by various users. No matter which variables are built into the model, some users will not be satisfied because a variable which they consider to be significant is missing.

Any computer simulation model, including one which looks 25 years into the future, is not a model in the sense of a facsimile, a physical model, or a manikin. It is a set of abstract representations which are manipulated by some formal discipline, such as logic or mathematics. In developing such abstract representations of the real world, a number of transformations must necessarily take place. Such transformations must necessarily serve to reduce the acceptability of the model to most users.

Feasibility of Computer Simulation Model for Predicting Manning Requirements of Post Year 2000 Ships

What then can be said relative to the utility and feasibility of a computer simulation model which will predict the manning requirements for post year 2000 ships? Certainly, the development of such a model is possible. The introductory section of this chapter indicated few requirements which cannot be met, and the section headed "Applicability of Digital Simulation" supported stochastic models for manning prediction. On the other hand, the section titled "Other Considerations" implied a number of reservations. How then may the two sections be reconciled?

The system planner needs the type of information provided by such models. Such a digital simulation model would provide a variety of information needed for planning purposes. Moreover, such information is not available from other sources. While the output of such models may be more at the "currently probable" than at the "eventually certain" level, the information provided by such a model will be better than nothing at all, possibly better than some might anticipate, and certainly superior to "engineering judgment." While such a model may be imperfect, it will probably be sufficiently perfect to allow the development of the insights required for system planning purposes.

IV. POSSIBLE MODEL CONCEPTS

Prior chapters attempted to place into perspective current automation trends in Navy ship systems and the implications of these trends for a stochastic digital simulation model which will predict manning requirements for the post year 2000 era.

The current chapter presents overall descriptions of conceptual approaches to models which seem to possess potential for providing the required manning estimates. Four different approaches are described: (1) a volumetric approach, (2) a technological extrapolative approach, (3) an automation approach, and (4) a linear programming approach. It is not held that the approaches are mutually exclusive and no attempt is made to evaluate comparatively the various approaches. In fact, the "best" approach may be some combination of the several approaches. For example, the linear programming approach cannot stand on its own and is best considered as a component of one of the other concepts. Moreover, the approaches presented are based on the creative thinking, knowledges, and predictions of the present program team. Others may conceive parallel or even radically different approaches.

The Volumetric Model

There were several specific indications in Chapter II that a number of changes can be anticipated which will affect the space required for each ship subsystem function:

- the space required for equipment will vary, depending on the state of automation
- the number of operators required to man each ship subsystem function, and hence their requirements for space, will vary with automation/integration
- maturing technologies will result in combining formerly separate functions which can be performed with common equipment

The volume required for each ship subsystem, changing through time as a function of these factors, is a matter of concern because of the very limited degree to which the volume of a ship can be modified, once the ship has been built. Superstructures can be added and hulls lengthened, but only at great cost and at the risk of impairing performance.

Concepts

In principle, it should be possible to forecast the changes over time in the space required by the equipment which performs each function. These changes in required space result from advances in the degree of automation. Likewise, it should be possible to forecast the changes in the number of crewmen required in concert with hardware volume changes. Given a fixed total volume, the space available for each crew member can then be computed.

This calculation is complicated by the fact that the space required per crew member for the performance of his work will vary with the function. In addition, the degree to which each function is impaired by a reduction in the number of personnel performing the function will also differ from one to the next.

Approach

The primary difficulty to be overcome is that forecasting volumetric and manning requirements of each ship function rapidly becomes a matter of conjecture and opinion as one looks much further than a few years into the future. As indicated by the interview data reported in Chapter II, it is doubtful that even two specialists in the technology of a given function would independently make similar predictions beyond the next five or ten years.

As a means of overcoming this problem, the volumetric approach would simulate changes for a large number of hypothetical functions. Each such function would be characterized by a number of parameters throughout the desired time interval. The simulation would then compute the volume available for each crew member for each ship subsystem function throughout the interval of time (say, 25 or 50 years). Enough information would be provided to estimate the effectiveness of performance of each ship subsystem function as it varies during the period of time studied.

Typical curves representing the variation with time of the volume required for the hardware associated with a ship subsystem function are presented in Figure 3.

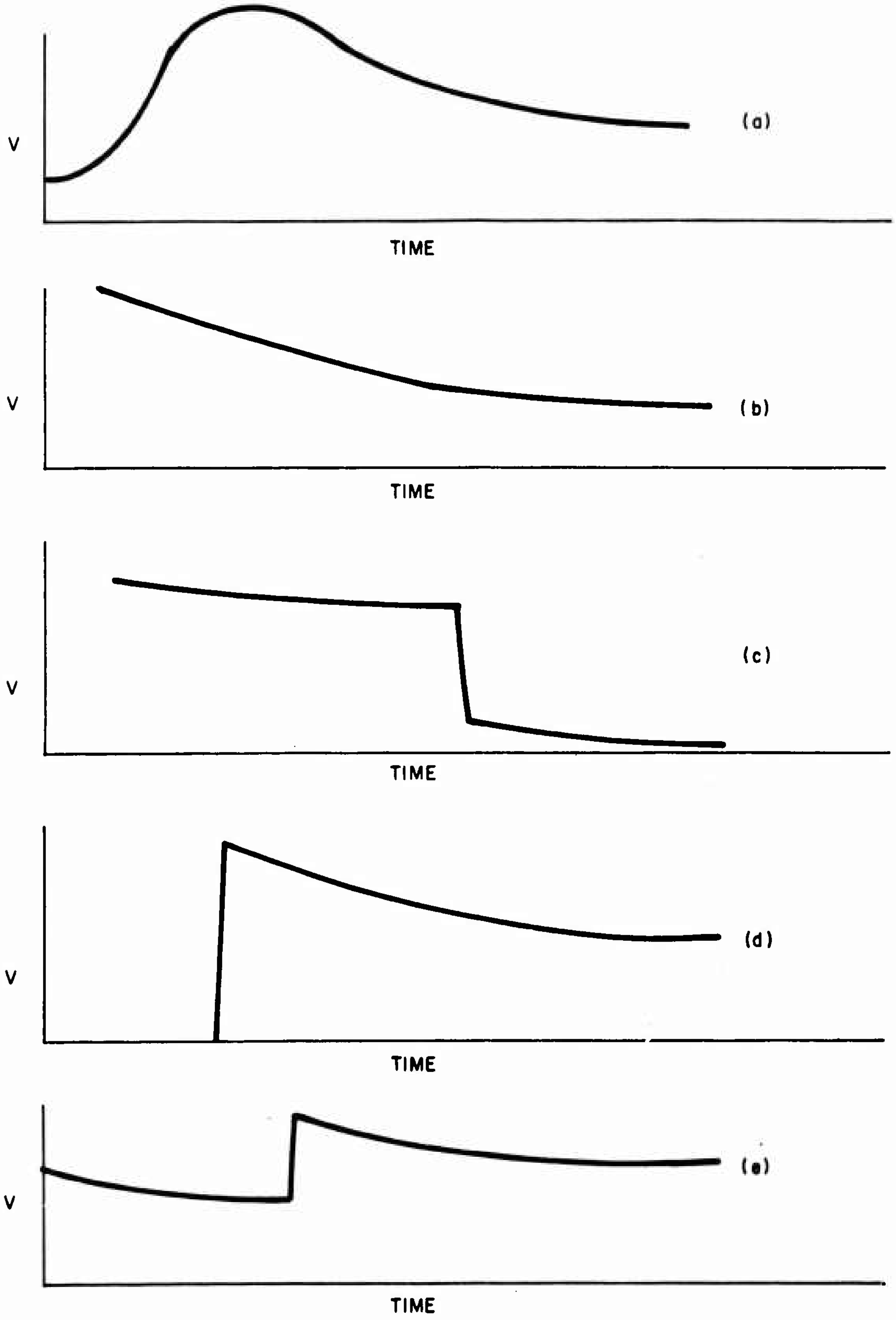


Figure 3. Curves representing variation in equipment volume over time.

- curve (a) shows a dramatic increase followed by a slow decrease. This behavior typifies data processing, in which early computers were very large, but later became more powerful and physically smaller.

- curve (b) might represent a mature shipboard subsystem function, such as food service, in which fast cooking ovens and availability of conveniences reduce preparation space requirements

- curve (c) represents a function which is consolidated with another, e. g., the consolidation of two computerized functions into the same computer

- curve (d) represents an entirely new function which technology has brought to life and which is gradually reduced in size through improved maintenance, packaging, and miniaturization

- curve (e) might be a shipboard subsystem function which has been extended in scope and capability so that it requires more equipment. An example might be a new type of sonar with greater sensitivity, range, or discriminating ability.

It is likely that additional models of volume change over time can be developed. Furthermore, combination curves can be synthesized, since several types of change can be expected to occur within a single shipboard subsystem function over a period of 25 years or more.

Different models for the variation in the number of crew members for a shipboard subsystem function with time can also be constructed. In many cases, variations in the number of men required will parallel the variations in equipment size. For example, the introduction of a new equipment type may require a corresponding increase in crew size to use and to maintain the equipment. As the equipment becomes more reliable and more automated, fewer men would be needed for manual control and maintenance [e. g., volume curve (d)]. In other cases [e. g., volume curve (b)], the number of crew members might remain constant, indicating that a reduction in size is taking place, but not an increase in automation. In still other cases, there might be a significant increase in manpower with time. This might be due to a rapidly growing versatility of the function, providing for more information requiring human processing, presumably with a sufficiently high payoff to justify the additional personnel.

No difficulty shoud rise from the fact that the hypothetical functions do not directly correspond with real functions. The mimicking of real function variation with time becomes very tenuous when one considers the future. By postulating a number of hypothetical functions, each characterized by plausible behavior patterns, the overall effects of automation can be estimated.

Furthermore, real curves can also be implemented. For example, a careful analysis of the fire control subsystem function may produce a real curve for a period of, say, 25 years. Data for this curve can be added to that of the hypothetical functions.

Assumptions

The problem in any simulation is to simplify the model without rendering it meaningless or distorted. One assumption that has been made is that crowding factors can be uniformly distributed as shipboard subsystem volume requirements increase and decrease in time. In effect, the assumption is equivalent to having a significant degree of flexibility in the internal arrangement of a ship. This might be brought about either by relocating bulkheads, by relocating functional areas, or some combination of the two.

Another assumption is that the relative space required per crew member is invariant as available space expands and contracts. For example, if the navigation function requires 1.5 times as much space per crew member as the CIC function, this ratio is constant, regardless of the degree of crowding. The only exception is that there is an irreducible amount of space below which the space per crew member may not fall.

Input Description

Within such a predictive model, a number of input variables are required to describe the general conditions of each run:

1. run identifier
2. date
3. experimenter (optional)
4. comments (run description) (optional)
5. initial year simulated
6. duration of run (in simulated years)
7. intervals between successive volume computations (in simulated years)
8. maximum crowding coefficient (maximum degree of crowding of crew members to be permitted)
9. chronological print suppression key (if set, results will not be printed out year by year)

Any number of ship subsystem functions, real or hypothetical, may be simulated, up to some realistic total. Each shipboard function consists of data which are constant throughout time and a large body of data which varies with time. The constant data for each function are:

1. function name (optional)
2. urgency of function - The urgency parameter will be used in the computation whenever the number of men required for optional manning exceeds the space available. In this case, the number of men associated with less urgent functions will be reduced proportionally.
3. function print code - This code determines whether data for this function will be printed throughout all years at the end of the simulation.

The bulk of the data describing each shipboard function are variable with time. For each shipboard function, the variable data consist of:

1. time (year)
2. equipment volume (cubic feet)
3. number of personnel required
    - for optimal performance
    - for satisfactory performance
    - for emergency performance
    - for maximum performance
4. space required per crew member

The number of persons in the various categories in item (3) are initially specified to provide a means to reduce the number of personnel manning the various shipboard subsystem functions, under the condition that overcrowding would otherwise result. Initially an attempt is made to man all functions with the optimal number of personnel. If space is insufficient, the least urgent functions are selected, and the number of personnel in each is reduced from the optimal number to the satisfactory number. If this results in a feasible solution, no further reductions are required. Otherwise, additional personnel are deleted, a process that continues until the crowding condition has been alleviated.

The variable in item (4) provides the amount of space required by each crew member to perform his duties. Normally, this will vary from one ship subsystem function to another. It is also somewhat elastic, so that if it is reduced, the function can still be performed. This is described in greater detail below.

The simulation also assumes that when crowding occurs, it is distributed uniformly across all shipboard system functions. The limit on crowding is reached when the degree of crowding is greater than that which is permitted by the maximum crowding coefficient. No further crowding is permitted; instead, the number of crew members performing one or more functions must be reduced.

Processing Method

Figure 4 presents an overall flow chart of the volumetric model simulation. All data required for a simulation run would be read in for each run. The alternative, embedding much of the data in the program, seems too inflexible. However, entry of required data from a file or data base is possible, provided that storage is available and the data are not subject to many changes.

Because of the errors which can enter into input data preparation, a number of error detection verifications are made. Examples of the types of checks which might be made are:

- interval between years is smaller than run duration
- if chronological print suppression key is set, the function key for at least one function must be set (otherwise no output is generated)
- function urgency has permitted value
- all volumes are positive
- for numbers of personnel in a given year, the sequence of optimal, satisfactory, and minimum numbers must decrease

Any errors detected result in an explanatory message being generated and the termination of the run. The print cover page subroutine (Figure 3) prints the run identification information. The compute initial year volume subroutine fixes the total volume. This volume remains constant throughout the run. The computation consists of summing the equipment volumes for all functions for the initial year. To this is added the optimal number of crew members required for each function, multiplied by the space required for each crew member performing the function. If the chronological print suppression key is set, the print results of year module is skipped. Otherwise, the space required for equipment and crew members for each function is tabulated and totaled from input.

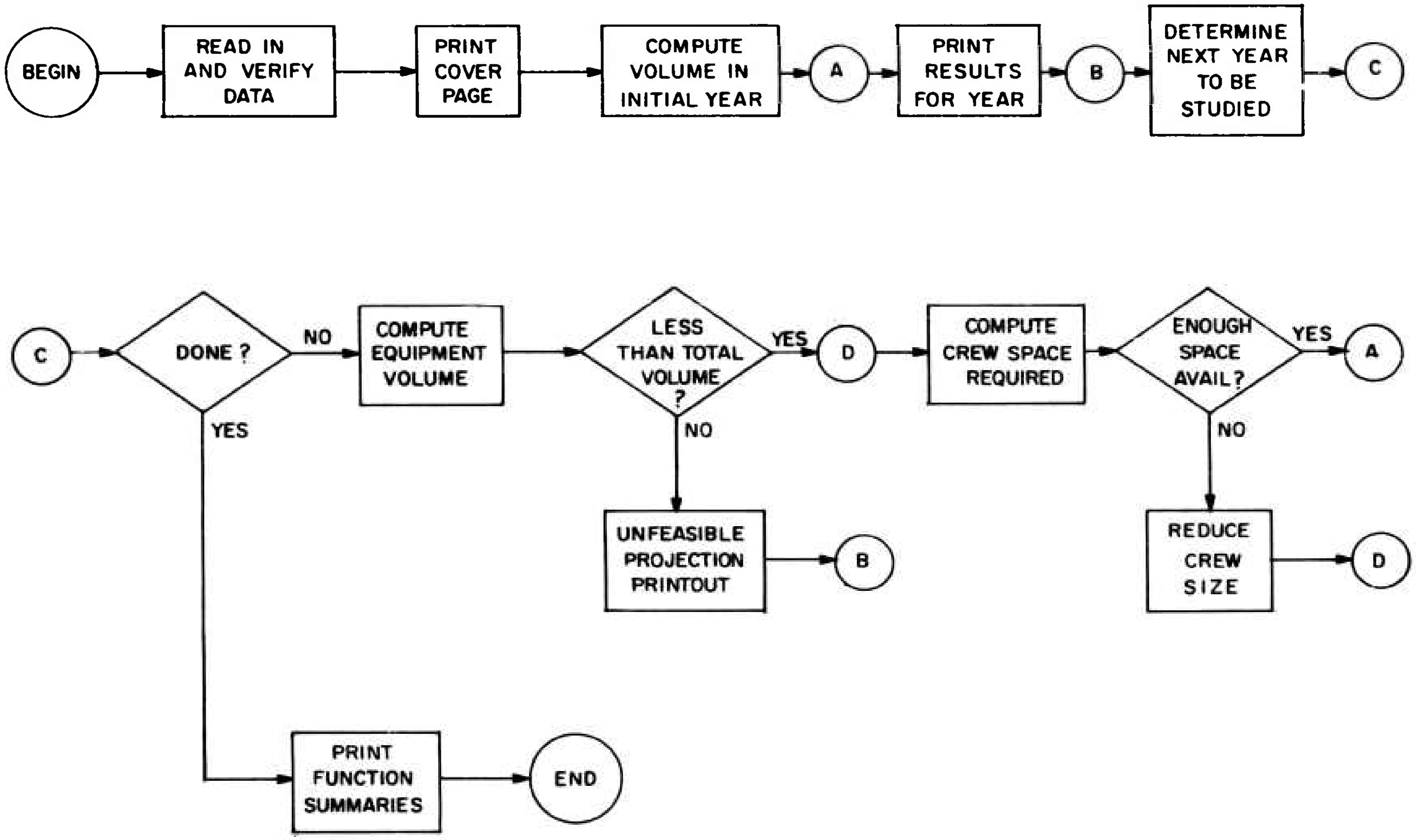


Figure 4. Volumetric model simulation flow.

The determine next year to be studied step (Figure 3) simply implements the next higher value. Assuming that the newly computed year is within the space of this run, the compute equipment volume requirements for the current year are summed. If the input did not contain equipment volume data for this year, a linear interpolation/ extrapolation would be made.

If the total equipment volume exceeds the total available volume, then clearly an unfeasible situation has resulted, since no space is available for crew members and an unfeasible situation printout is generated. This printout is generated even if printing is normally suppressed. Control then passes back to the time incrementing mechanism.

If the equipment complement for the current year is less than the volume of the ship, volume required for the crew in the current year is computed. The initial calculation assumes the estimated optimal number for all functions.

An attempt is made to crowd the crew into the available crew space. This is considered to be the difference between the total ship volume and the volume required for the equipment. First, the ratio of available crew space to required crew space is taken. If the ratio is unity or greater, the space available is sufficient, and the result can be printed out. If not, it will be necessary to reduce crew size. Accordingly, two different measures were included in the input to provide a stepwise and selective way to reduce the number of crew members:

- a measure of the relative urgency of each shipboard function
- four levels of manning each function. These vary from optimal, through satisfactory, to minimal.

Crew size reduction takes place one step at a time. After each step, a computation is made to determine whether crew size has been reduced sufficiently to fit the available space. The stepwise reduction proceeds as follows:

1. all crews in the function of least urgency are reduced from their optimal size to satisfactory size
2. same for all crews in next least urgent function

.
.
.

(n) same for all crews in most urgent function

(n+2) repeat for stepwise reduction from satisfactory to marginally acceptable

Since the safeguard exists that at least some space must be available for the crew, the above process will eventually terminate. Then the results for that year are printed out. At the conclusion of simulations for all years, the simulated histories of designated functions are provided as output. This printout is basically the same information printed in the chronological summaries, but sorted and reprinted for each function of interest in turn.

Output

Three distinct outputs are generated by the simulation. The first output summarizes the basic information about the run, containing optionally any comments which the experimenter wishes to include.

An extension of the record is a set of error messages related to the data validation step. If any such errors are found, the run is terminated at this point.

A second printout (if not suppressed) contains yearly results starting with the first generated base year and continuing for every interval thereafter. It provides the following information for each ship subsystem function:

1. function name
2. equipment volume
3. manning level (optimal, satisfactory, etc.)
4. number of men
5. total crew volume
6. percentage of total volume dedicated to the function

For the time simulated, the overall crowding factor and total volume of the ship are given.

A special section of this type of printout is required when no feasible solution is possible. It consists simply of an explanatory message, the total volume, and the computed equipment volume.

A third printout provides, for each shipboard subsystem function explicitly flagged, a tabulation of the history of the function. This consists of the year plus items (2) through (6) above.

In the event of an unfeasible solution in any given year, items (2) through (6) are replaced by an explanatory message.

Risk Assessment

There appears to be little question as to whether or not implementation of the model is feasible. The program structure is straight forward and the contents of individual program blocks are fairly simple. Note also that alternative algorithms for crew size reduction, crowding, etc., can be substituted without requiring more than minimal changes to other program blocks (primarily the verification and printout subroutines).

The primary advantages of such a model is its relative simplicity. It has a strightforward structure, containing a number of mutually independent, replaceable modules. The input parameters are easy to prepare and to change, and the outputs are simple to interpret. The learning time required for effective use should be limited to a few hours. The running time required is also relatively minor. Thus, many insights into the possible implications of automation on ship accommodation may be gained at minor costs in time and computer utilization.

The primary disadvantage of the model is the reverse of its primary advantage: the simplicity of the model results from its simplifying assumptions. One basic assumption was that volumetric changes on shipboard brought about by automation can be approximated by a large number of hypothetical input functions, changing independently but interacting. This, of course, is a weakness of the input more than of the model. However, if trustworthy input cannot be obtained, the value of the model itself becomes questionable.

Another assumption which must be examined carefully is the assumption that the space can be allocated among functions in such a manner that crowding can be distributed uniformly throughout all functions. The volumetric model could accommodate a more realistic algorithm for the distribution of crowding, but such an algorithm would require a prioritization of the importance of each function relative to the various goals of the ship simulated.

The Automation Level Model

The automation level model is based on the concept of extrapolating levels of automation into the future for various ship functions, so as to enable future ship man-machine effectiveness values to be estimated by calculation. The essential purpose of this simulation model is similar to the others presented--the numerical prediction of manning requirements for ship/crew systems which may be implemented more than 25 years in the future.

The approach first involves determination of the total amount of effort required to be performed over all of the various shipboard subsystem functions during one watch or shift on the ship to be simulated. The determination is made as a function of the level of automation of each ship subsystem function for the time period to be simulated. This workload requirement is then used to evaluate how well the actual assigned crew complement does its job, taking specified environmental, mission, and related conditions into account.

In this approach, the following factors are considered in each stochastic computer simulation:

- ship type/capability/class
- type of mission
- length of simulated shift (watch)
- personal characteristics of crew
- level of automation of ship functions, or year(s) to be simulated
- environmental conditions

In defining the scope of this approach, it is pointed out that the following are not considered: personnel tasks and rates, level of expendable (consumable) supplies, leadership qualities of personnel (except as inherent in their proficiency ratings), navigation (ship location, except as inherent in the geographic zone simulated), distance traveled, and the physical dimensions of system stations, or the ship itself.

Input

The types of data required as input to this model are given, together with a brief description of each, in Table 4. The concept is one in which an analyst is provided with the opportunity to request individual computer simulation runs either through terminal keyboard entries or submittal of input card decks. A run consists of a single ship/mission simulation, in which input values are used as provided; or, a series of simulations in which several ship simulations are made during which values of selected inputs are varied over the simulations in some prespecified way. In each simulation run, the user sets conditions by specifying values for the input data items shown in Table 4.

Table 4

Types of Input Required

Input Label	Description of Input Data
Ship Type/Class	One of a preselected set of ship types. Either name or abbreviation will be acceptable.
Duration	Number of hours (1-8) to be simulated. The simulation of a single operational watch is believed to be adequate for the type of global results desired.
Mission Type	One of a preselected set of mission types.
Ship Functions	Ship functions to be simulated; when "unknown" functions are specified, the techniques described in the volumetric approach may be used to select functions to be simulated.
Number of Men	The number of men which are required to man the corresponding ship functions today, i. e., at current levels of manning.
Average Crew Speed	A value which identifies the work pace of the average man in the crew to be simulated.
Per Cent Crew Fully Qualified and in Training	Two values from 0 to 100 to specify the proficiency of the crew.
Cross Training Probabilities	A matrix indicating the likelihood of each personnel type being cross trained with each other type.
Sea State	A code from 1 to 9 indicating the sea conditions to be considered.
Level of Automation	Either: (1) the desired year of simulation, or (2) specified models for each ship function (see volumetric model) or (3) specific values of the automation levels for each ship function to be simulated selected from the following: 0 - fully manual 1 - slight automation 2 - moderate automation 3 - high automation 4 - fully automated
Teach	A request for instruction by the analyst on how to provide input data for this model. This allows the analyst to request either the computer's extrapolation of automation levels or to provide specific values.
Run Identifiers	Date, experimenter, or other simulation run identification.
Output Detail Outputs	Level of detail of printed results.

Thus, we conceive of sessions during which the analyst would submit sets of data representing requests for a series of runs so as to compare results which are generated by virtue of different input parameters. In this way, the analyst would be able to determine the effect of changing one (or more) input parametric values such as:

- greater or lesser values of automation
- better or poorer qualified crews
- level of mission difficulty
- the future year which is to be studied

Processing

Utilizing the input data provided for each mission/watch simulation run, the automation level model would perform the sequence of calculations shown in Figure 5. In Figure 5, the major program modules are named. A brief description of each module follows:

Initial	Performs initialization of variables/arrays required for the start of each simulation run.
Read	Scans and reads and checks syntax of input requests and data. Sets up default (unspecified internal values). Reports any errors noted. Usually will terminate if these are errors.
Reset	Sets appropriate initial values of all global data items for each iteration of the run.
Extrapolate	Projects the level of automation to be simulated for each ship subsystem function. This is required only if option (1) of level of automation input is selected. If option (2) is selected, the automation levels given are employed. The technique proposed is elaborated on here due to its high relative importance to the model. Consider an automation level P, which has values between 0 and 1, such that:

$$P = 1 - \frac{n}{N}$$

where n is the number of men needed and N is the number of men needed for the no automation case. Thus, $\frac{n}{N}$ is the fraction of the men required for automated operation as compared to "manual" operation:

$$n = N(1 - P)$$

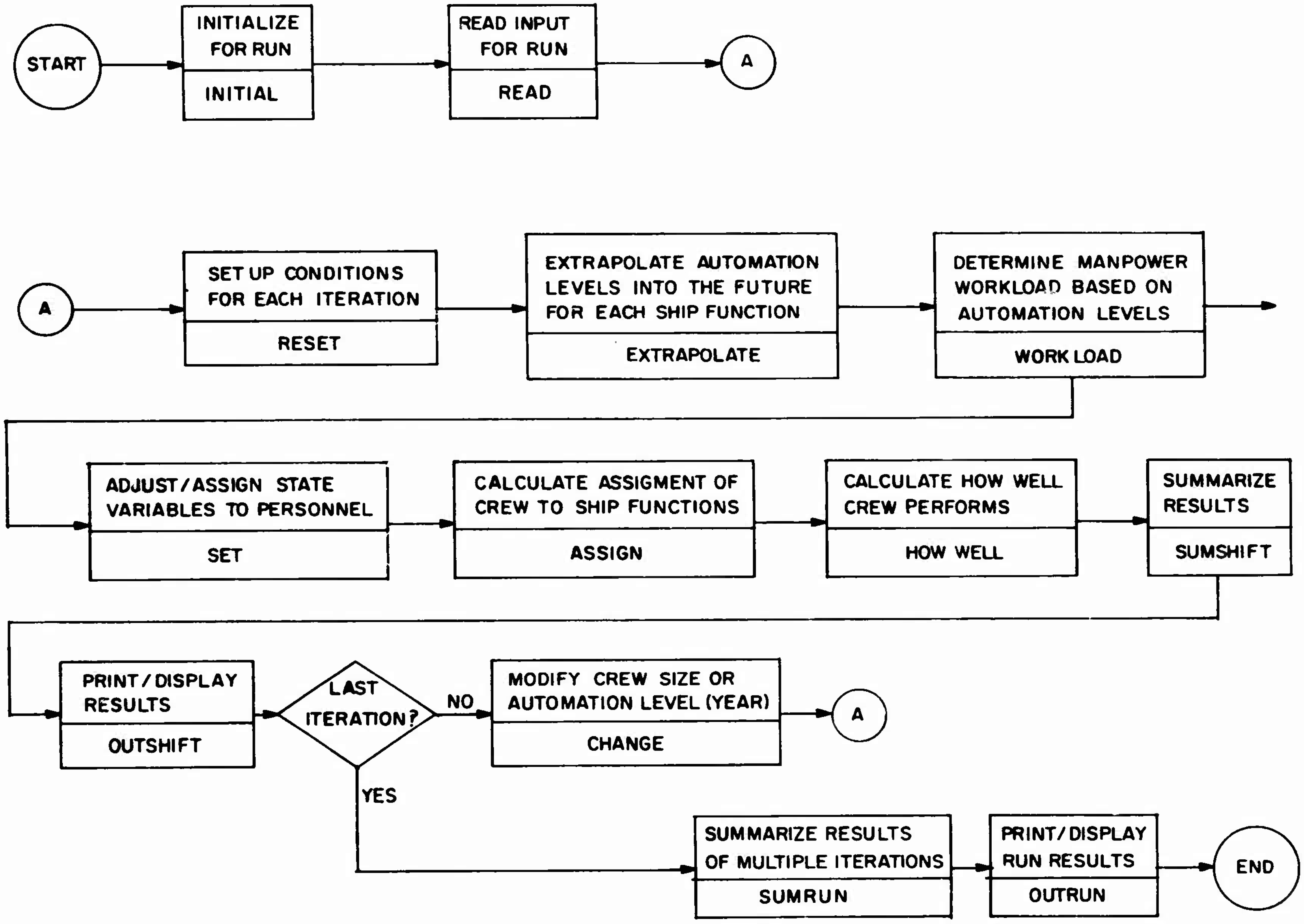


Figure 5. Automation model simulation flow.

If n_0 men are required for an automation level of P_0, then

$$N = \frac{n_0}{1 - P_0} \quad \text{and } n = \frac{n_0}{1 - P_0}(1 - P) \text{ for any } 0 \leq P \leq 1.$$

Suppose that when automation equals .2, 4 operators are needed.

$$n_0 = 4, \ P_0 = .2, \ \text{so } n = 5(1 - P)$$

Then, if $P = .6$, $n = 5(1 - .6) = 2$ operators are needed. If n is not an integer, this would imply time sharing of men (rounding to integer value).

In Chapter II, values of automation were estimated for the present time and for some future time. These yield two points on the automation-as-a-function-of-time curve:

$$(0, \ P_0), \text{ and } (t_1, \ P_1).$$

If a suitable function is fitted to go through these points, it is possible to interpolate and extrapolate the values of automation level. It is suggested by Ayres (1969) that "Qualitatively, one can see from Figure 5.4 that the curve of progress in a field is likely to have a stretched-out S shape. A phenomenological model developed by A. L. Floyd based on concepts akin to the foregoing (discussed in Chap. 7) tends to confirm this surmise" (p. 84).

On p. 123, Ayres lists several growth law formulas. These were investigated for their behavior and ease of curve fitting. The logistic (Pearl) curve, an S-shaped curve whose range is from 0 to 1 (not inclusive), as t goes from $-\infty$ to $+\infty$, was considered best suited to the representation of automation levels. The curve is asymptotic to the lines $P = 0$ and $P = 1$ so that the no automation and complete automation cases are never actually achieved. The formula is:

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

If at $t = 0$, $P = P_0$, and at $t = t_1$, $P = P_1$, the formula becomes:

$$P = \frac{}{1 + (\frac{1}{P_0} - 1)\left[\frac{P_0 \ (1 - P_1)}{P_1 \ (1 - P_2)}\right]^{\frac{t}{t_1}}}, \quad P_0 \text{ and } P_1 > 0.$$

This allows the calculation of P for any other value of t.

Examples: Suppose $P = P_0 = 0.25$ at the present ($t = 0$) and
$P_1 = P_1 = 0.5$ when $t - t_1 = 25$ yrs. (from now)

$$\text{Then } P = \frac{1}{1 + 3\left(\frac{1}{3}\right)^{\frac{t}{25}}} \qquad : \text{ CASE A}$$

Suppose $P_0 = 0.25$ and $P_1 = 0.75$ when $t_1 = 25$
(years into the future)

$$\text{Then } P = \frac{1}{1 + 3\left(\frac{1}{9}\right)^{\frac{t}{25}}} \text{ or } \frac{1}{1 + 3(3)^{-\frac{2t}{25}}} \qquad : \text{ CASE B}$$

Suppose $P_0 = 0.1$ and $P_1 = 0.8$ when $t_1 = 25$

$$\text{Then } P = \frac{1}{1 + 9\left(\frac{1}{36}\right)^{\frac{t}{25}}} \text{ or } \frac{1}{1 + 9(36)^{-\frac{2t}{25}}} \qquad : \text{ CASE C}$$

Each of these is plotted in Figure 6. In the first two examples, the curves between the given points are practically linear.

If $t = 0$ represents the year 1975, then $t = 25$ represents the year 2000. Note that the inflection point appears to occur when $P = 0.5$.

The data from Chapter II indicate that, based on a sample estimate of nine advanced scientists, Case A (25 per cent automation now and 50 per cent automation in 25 years) is a useful initial approximation.

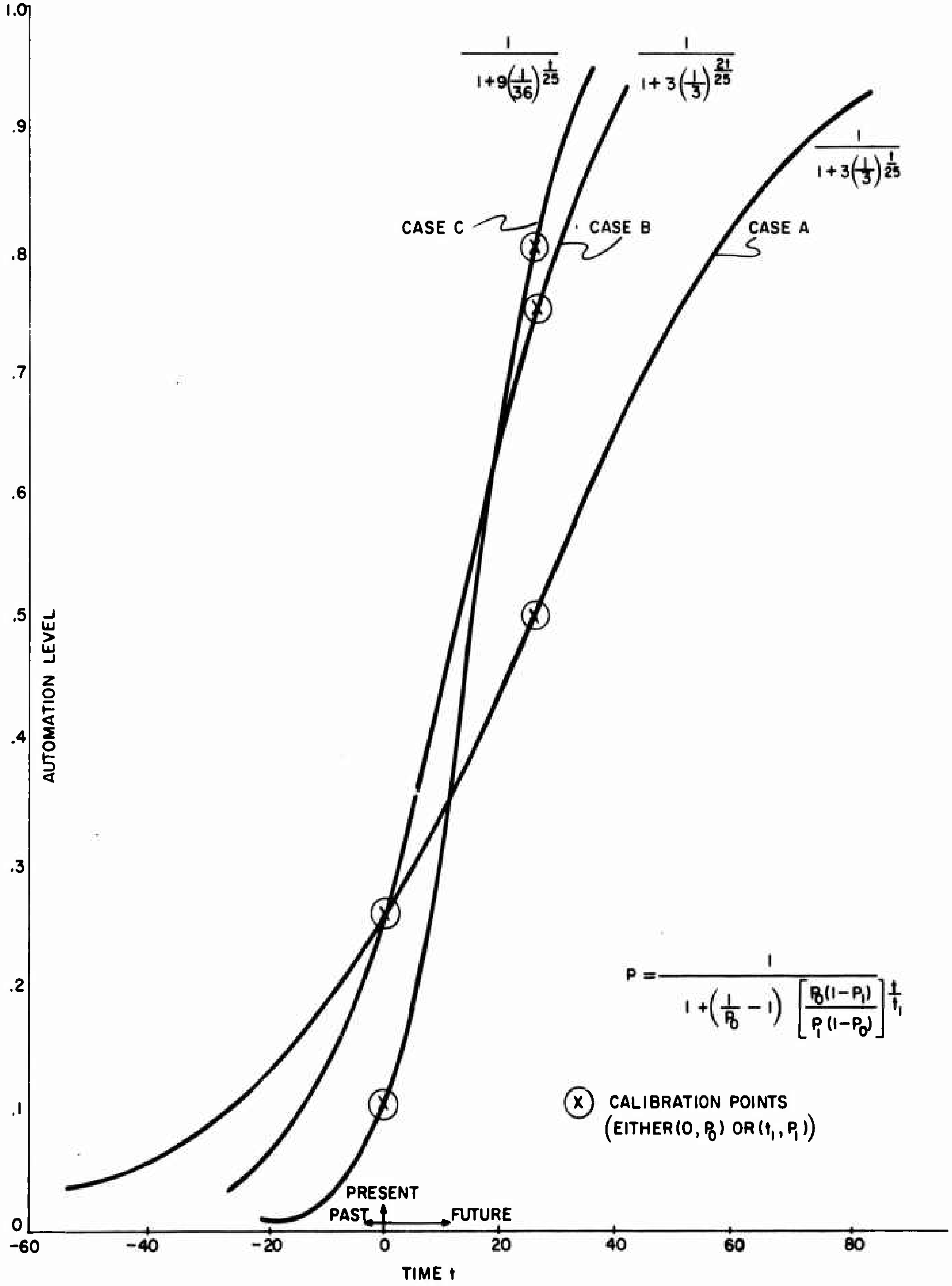


Figure 6. The Logistic (Pearl) Method for extrapolation of the future levels of automation.

Workload	Calculates the manpower workload (including sleep and relaxation) which must be devoted to each ship function for satisfactory ship system performance. This is determined as a function of the automation level to be simulated in the input data.
Set	Calculates and assigns specific values of speed and proficiency from input averages. Determines cross training for each man in view.
Assign	Determines the allocation of each crew member to one or more ship functions (see linear programming approach, page 64).
How well	Determines how well each ship function is performed as a function of the men assigned and the manpower workload required. Also taken into account are sea state, crew qualification levels, and crew speed. Output measures may be in the form of accuracy, thoroughness, or responsiveness.
Sumshift	Summarizes the results for the current crew and automation levels.
Outshift	Generates tabular or display output of current crew/automation level iteration.
Change	Steps parameters for crew size or automation level for next iteration.
Sumrun	Summarizes results over all iterations.
Outrun	Generates tabular or display output of all specified iteration simulated runs.

Output

Following the basic calculations of each simulation, output recording would take place at a variety of levels of detail. Examples of the general levels of detail to be available are:

- function results
- end of simulation results
- end of run results

Output would be available either at the terminal where the analyst submitted his input or, for local batch runs, at the computer center.

The following information would be available:

1. run/simulation identification information
2. level of automation projected for each function
3. crew performance by ship subsystem function as a function of manning
4. ship system efficiency values as a function of manning
5. minimum, average, and maximum data values as a function of manning
6. distribution of personnel time by function/duties as a function of manning
7. assigned values of psychosocial values for each crew member
8. areas of over or under manning
9. utilization of personnel in crosstrained specialties as a function of manning

The Technological Extrapolative Model

Each of the two prior approaches, the volumetric model and the automation model, to the problem of forecasting the ship manning requirements for the post year 2000 era rested on extrapolations and insights relative to trends towards automation. The technological extrapolative model rests on a similar set of extrapolations. However, in this case, the extrapolations are based more on individual technological developments and less on automation, per se. Accordingly, the technological extrapolative model is introduced with a set of conjectures relative to changing technology. These are introduced as examples of the types of thinking which underlies the belief that technological changes will impact what crew members do aboard ship. Although the two concepts, automation and technological change, possess something in common, there is also a difference between the two. Specifically, by technological extrapolation we mean the effects of an increased scientific and production capability regardless of whether or not the function served by the capability is automatically or manually performed. The manning requirements resulting from technological changes will necessarily be different from manning changes which result from automation.

Electronics

The conclusion may possibly be drawn that virtually all the information concerned with the day-to-day operation of a ship will be handled, at least to some extent, by electronic processes in the post year 2000 ship. This information processing may be as simple as the video transmission of a championship football game or as sophisticated as the validation of the genuineness of an apparent command decision. There are a number of trends in the electronic arts which support this conclusion. Remarkable miniaturization has been made possible by integrated circuits. At this point in time, the ability to build general capability into moderate size integration gives us essentially a powerful user defined minicomputer which may be programmed to do a host of apparently related tasks (ranging from automative non-skid brake systems to devices to interpret a whole body radioisotopic scan). This trend may be expected to continue. LSI (large scale integration) techniques are very likely to make available powerful medium size (size here refers to year 1975 size) computer systems which by the year 2000 would actually occupy very little space. This physically small, but powerful, computer would probably have the capability of performing many of the essential information processing steps which will be needed on the ships of the twenty-first century.

Additionally, analog advances cannot be ignored relative to electronic development, although the need for consideration of analog circuitry may not be obvious. The actual information, unless it is of a very simple nature (e. g., number of times a door opens and closes) or unless it is transmitted through a data link, is analog in nature. Significant, but much less widely publicized, advances are occurring in analog data collection and manipulation. One of the reasons for this is the advent of a number of very high gain operational amplifiers which, when used with the proper high levels of negative feedback, produce highly believable amplifiers. The field of analog signal processing has received major help from the idea of active filtration (using an amplifier to actually filter out unwanted signals) and phase lock amplifiers (the ability to tell an amplifier, on a continuing basis, which signal component to amplify). The full impact of these and other new analog devices is probably not yet realized even by specialists. These analog devices (operational amplifiers, active filters, and phase lock amplifiers) have been attempted for some time but the rapid practical development did not occur until the development of integrated circuits. The following difference seems noteworthy. The advent of digital circuit integration has led to much smaller digital devices with broad, but not new, capabilities. On the other hand, for analog devices, circuit integration has led to qualitatively different, previously unavailable, analog devices.

However, the major impact will be realized when the new sophisticated analog signal acquisition and processing techniques are teamed with powerful but small digital computers. The result could be routine performance of signal acquisition/processing/interpretation on a scale not now projected by most people.

Electronic Signal Processing

By electronic signal processing, we mean, in the present context, the eduction of information from noisy repetitive signals. Some of the presently available signal processing techniques which are likely to be of future utility are signal averaging, signal correlation, and signal anticorrelation.

Signal averaging takes a noisy signal in which the desired information may be totally unrecognized because the signal to noise ratio is very low (much less than one) and:

1. processing it faithfully on an analog basis so that minimum degradation of the signal takes place, then

2. converting from analog to digital format, and then

3. feeding the digitized information repetitively into a digital computer with a time domain memory

Signal enhancement occurs because noise (being randomly both positive or negative, but not both simultaneously) tends to cancel on successive passes through the computer, but repetitive signals build up on each pass through the computer.

One obvious application could be passive sonar where a low sound of a moving ship is picked up, the signal processed, and then averaged signals compared with a library of known signals by an identification system. For this purpose, the human would be out of the signal acquisition loop because he would not be able to detect the presence of useful information until after it had been found by the signal averager. While skilled operators might still be needed, their role would be to exercise such systems and verify that they are operating properly. Human operators might also be used to establish the search parameters to fit a given tactical situation.

Signal correlation and signal anticorrelation are also powerful techniques which probably have very advanced uses. Until recently, signal correlation and anticorrelation have been mostly laboratory techniques. Simply stated, a signal correlator looks for some signal which possess a correlation with a known event. This correlation is often temporal. A signal anticorrelator looks for signals which do not have a correlation with a known event. The use of these two techniques would seem to have considerable potential for applications in many new and existing systems such as IFF, detecting and recognizing signals from countermeasures (both active and passive), and validating the authenticity of received command messages. Again, such systems could require highly trained personnel to serve not as links in the signal processing, but to perform system test, exercise, and monitoring roles.

Computer Systems

The subject of digital computer capability and availability was mentioned in a number of prior sections of this report and need not be elaborated on here. However, we again note that: (1) speeds of individual operations are increasing, (2) memories are expected to become much larger, more flexible, and faster, (3) large scale semiconductor memory will certainly be possible, and (4) large scale more exotic memories, such as magnetic bubbles, seem likely.

Communications

Communications needs to be dealt with on two levels: secure and nonsecure. The distinctions between underwater and surface vessels is also important.

Underwater communications schemes in which either end of the link can initiate contact with the other end without compromising the security of the mission seems to be a difficult task. Progress on this problem is not known to the present authors. Accordingly, the remainder of this section is confined to surface vessel communications.

By using satellites, nonsecure communications should be possible at any time at the desire of either end of the link. Subject to the limitations of line-of-sight transmission and dependence on atmospheric conditions, the ship-borne laser-satellite link can provide a communication link with an enormously high information density. It should be noted that such a communications system could not be depended upon, by either end, as a call anytime system.

Secure transmissions pose two problems:

1. anyone, friend or enemy, may break the cypher, and
2. secure transmissions impose the requirement for detecting forged messages.

With the availability of many large scale computing systems, there is currently a sophisticated program of intercept/decypher taking place. There is, unfortunately, no way for one to know who is trying to, or succeeding in, breaking his cyphers. It should be noted that many individuals have access to large scale computing systems. The probability of any one person breaking a cypher may be very low but, historically, cypher breaking has happened many times. One suspects that cyphers are broken more often than is usually admitted.

If secure communications can be assumed, there are many implications relative to both the number of system operators/maintainers needed and their skill requirements. With a secure communication system, much equipment monitoring, routine check, and malfunction diagnosis could be performed by a land based system. In addition, the secure communications could be used for personnel skill maintenance and upgrading. The need for security is obvious during either system or human conversations with the land based system. We also note that such a system would need to include precautions against forged messages.

Lasers

Possible communications uses of lasers have been mentioned previously. By the year 2000, laser based systems will probably be relied on extensively for defense capability. Radar controlled laser ray systems may well be the only way to defend a surface ship against a supersonic aircraft/missile attack. Large attack ships may have laser weapons for short range or even medium range offensive use. Efforts are now in progress to develop a gamma ray laser system. There are some reasons to believe that such a system can be achieved. If it can be made intense enough, a gamma ray laser could represent a very significant device, because it could have great penetrating power and not be visible to the eye. The device would be as serious a consideration as gamma rays from nuclear devices but would have the added implications of coherent radiation. Some possible uses would include antipersonnel use, antielectronic system use, and antiwarhead use. However, we note that the idea of a gamma ray laser is speculative at this time. Laser systems are quite inefficient in converting electrical energy into optical energy. Accordingly, if lasers are to be used for either defensive weapons or for offensive weapons, they will require large supplies of electrical energy.

Miscellaneous

There are a number of other present technologies and some probable technologies which could effect the manpower needs of a naval ship of the post year 2000 era.

1. Display Systems--A number of versatile, high visibility display systems which do not use a cathode ray tube are being developed. Much more progress can be expected in this regard. Many of these systems use a laser or lasers to allow a legible information display.

2. Nonmetallic Technology--A number of non-metallic materials of high strength are under development. These could be used, for example, to make small drone aircraft which would be very hard to detect and to defend against. Such aircraft could be used for reconnaissance, to carry countermeasures, for signal jamming, and the like.

3. Satellite Surveillance--A fully operational satellite surveillance system would seem to have major implications for surface ships. Such a system could almost completely negate the historical elusiveness of ships on a large body of water. Conversely, a friendly surveillance satellite could not warn of an impending aircraft attack, for example, if its field of view is obscured by unfavorable weather conditions.

Approach Details

In the development of the technological extrapolative model, we begin with a consideration of ship types and ship manning levels currently known and employed or scheduled for deployment and identify those technologies of primary interest, Then, the current state-of-the-art in these technologies and the potential for still further advances of these levels are considered, along with such questions as:

What advances in these technologies canbe projected?

Which are of importance to ship subsystem design?

Are there other new technologies which can be expected to evolve during the time period under consideration?

This model has its predominant impact in the prediction of technological effects on levels of manning. As a result, this approach can be merged with one of the other models presented.

This model, too, does not consider personnel ranks/rates, expendable supply levels, personnel leadership qualities, ship geographical location, distance traveled or ship dimensions.

For the purposes of model description, the technologies listed in Table 5 have been identified as those which are expected to have principal impact on ship subsystem designs over the next 50 years. A more exhaustive list would need to be developed if this modeling approach was to be actually implemented. It is also noted that there is some interaction or interrelation between the technologies. Definition and description of this interaction would also need to be the subject of further work.

Table 5

Examples of Technology Areas

Technology	Comments
Electronics	integration, components
Signal Processing	signal enhancement, correlation, anticorrelation
Computational Sciences	computer architecture, signal processing, programming
Communications	operator interface devices, voice recognition, displays, radio, linguistics
Materials	chemical, metallurgical, optical, nonmetals
Satellite Support	space technology
Energy Utilization	atomic, chemical, solar, engine design acoustics
Lasers	communication, offensive weapons
Displays	improved man/machine interface

Input

This section presents a brief description of the types of input data which would be required by the technological extrapolative model. Here, as with the automation level model, the concept of simulating a ship/system by one or more simulation runs applies. The input would be composed of such items as:

Ship Type/Class	one of up to n preselected ship types
Duration	number of hours of watch to be simulated
Mission Type	one of n preselected types of missions
Technological Capability	data presenting the expected limit of the technological capabilities for each area of technology. A sample curve presenting this in graphic form for one technology is given in Figure 7.
Technological Availability	data presenting the expected level of technology actually available for each technology. These data indicate the extent of the average time lag between invention or technological proof of feasibility and the implementation of the technology. The lower curve of Figure 7 presents an example of such data. Periods of time in which the two curves show greater separation indicate periods of greater lag between "discoveries" in the sciences and incorporation of these results into engineering technology.
Ship Functions/Technological Dependence	a matrix similar to that shown in Table 6, which selects those ship subsystem functions to be included in the simulation and estimates the level of dependence of each ship subsystem on each technology area. Values selected as illustrative entries represent level of importance of the technological area to the functions. This includes an input defining the year (decade) to be simulated.
Number of Men Now	the total number of men required to man the corresponding ship subsystem functions at current (1975-1980) level of implemented technology
Average Crew Speed	a value specifying the speed of the average man in the crew to be simulated
Crew Size to Simulate	an initial estimate of the total number of men to be assigned to the ship of the future for simulated prediction of ship/crew performance
Per Cent Crew Fully Qualified	value which specifies the overall proficiency of the crew
Sea State	a code indicating the sea condition to be considered
Output Detail Options	instructions to specify the level of detail desired on printed output tabulations and/or displays

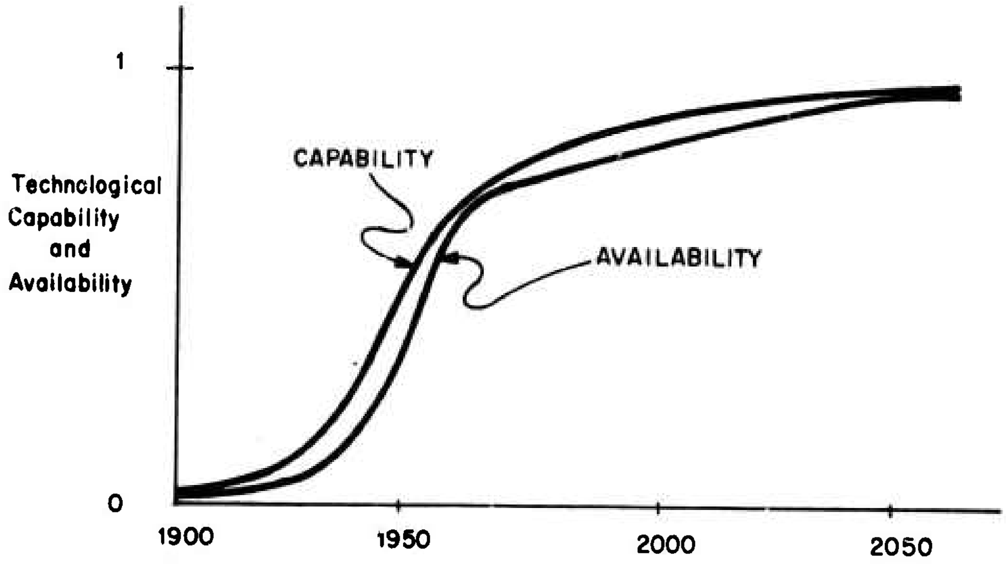


Figure 7. Technological capability and availability data.

Table 6

Example of Table of Ship Subsystem Function Dependency on Technology Areas

Ship Sub-System Function	*Technology Area*								
	Electronics	*Signal Processing*	*Computer Science*	*Communications*	*Materials*	*Satellite Supports*	*Energy Utilization*	*Lasers*	*Displays*
Navigation	3	4	2	4	2	5	1	3	4
Propulsion	1	2	2	1	4	1	5	0	4
Enemy Detection	5	4	4	4	2	3	1	3	4
Defensive Weapons									
Offensive Weapons									
Fire Control									
Communications									
Maintenance									
Air Operations									
Combat Duration									
Food Services									
Intelligence									
Training									
Recreation									
Admin.									
New Function - 1									
New Function-2									
:									
:									
New Function - N									

0 - no effect
1 - minor effect
2 - modest effect
3 - important effect
4 - very important effect

Processing

Utilizing the input data, the technological extrapolative model would execute the sequence of operations shown in Figure 8. Figure 8 shows each major program subroutine. A brief description of each of these subroutines follows:

Initial	performs initialization of variables/arrays required for the start of each simulation run.
Read	scans, reads, and checks the syntax of input run requests and data. Sets up default values and reports on input errors.
Techcapab	determines an interpolated value of technological capability from data provided for each technology area for the time period to be simulated (see Figure 7). Also determines technology gap from availabilility data for each technology.
Techlevel	determines the technology level predicted for each ship subsystem function based on the dependency data (Table 6) and on the technology capability and availability gap value described above. This will result in a numerical value representing the extent of technology employed for each ship subsystem function at the projected time period of interest. The contention here is that the level of manning on a military ship is a function of the technology level for each ship function and the ship type/mission. This is not to imply that greater technology utilization per se will result in reduced manning. In fact, this has not proven to be the case. Certainly, with the initial introduction of new technology to a ship subsystem function manning has often increased--for maintenance if not for operation. Also, the history of military vessels seems to show that new technology generates new methods to implement ship subsystem functions with regularity (for example, satellite navigation, atomic fuel propulsion, radar detection). This may also generate new ship subsystem functions. All of this introduction of new technology seems to generate at least "temporary" (5 to 20 years) need for an increase in manning in the ship subsystem function which is the beneficiary of the new technology. Thus, we conclude that manning increases in periods following times of high technological productivity in scientific fields which are useful to the ship designer and commander. The derivation of mathematical relationships to reflect these conditions will be part of any model development effort using the technological extrapolative approach. It will result in the calculation of level of technology for each ship subsystem function as a function of:

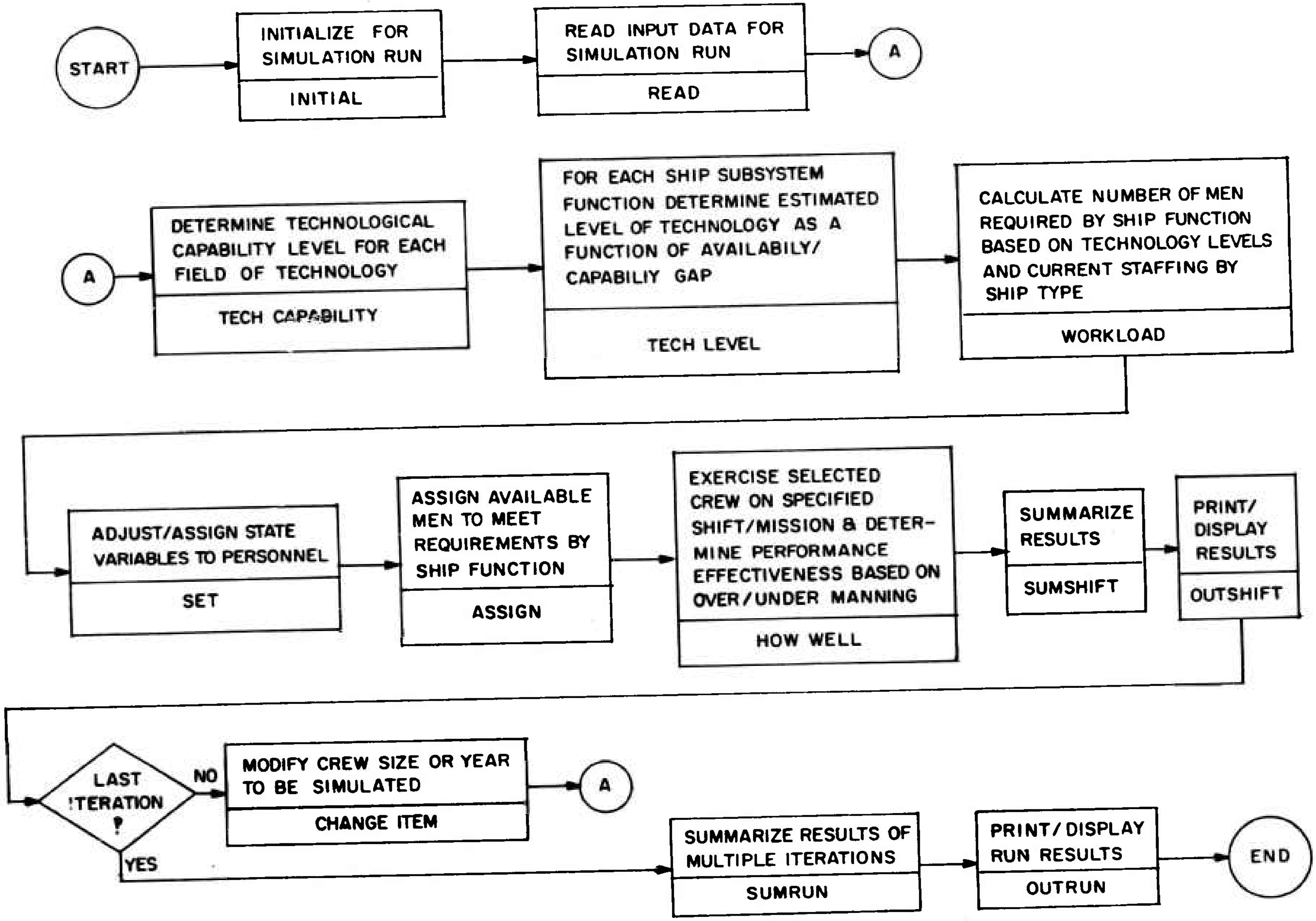


Figure 8. Technological extrapolative simulation flow.

1. technological capability value
2. recent changes in technological capability
3. gap between capability and availability
4. year to be simulated

for those technologies which are believed to affect the specific ship subsystem functions. The technique for the extrapolation and automation level into the future, described under the automation level model approach, would also be useful here.

Workload	armed with values for technology levels and other input data such as the present day manning requirement for ships of similar types and the missions to be simulated, the next program subroutine determines the number of men required to operate adequately and maintain equipment representing each subsystem function. This will probably be accomplished in such a way as to report the results for each of a small number (say 20 to 25) types of personnel.
Set	calculates and assigns specific values of speed and proficiency to each crew member using average values provided as input. Determines the crosstraining for each man in the crew.
Assign	determines the allocation of each available crew member to one or more ship functions. Personnel type and crosstraining are taken into account, but of greatest interest in accomplishing the assignment is use of available personnel to the maximum and to distribute any shortage over the ship functions in some reasonable way.
How Well	determines how well each ship subsystem function is performed/manned during the simulated watch. This determination is based on the manpower allocated vs. assigned, the sea state, and personnel proficiency. Output measures may be in the form of accuracy, thoroughness, or responsiveness.
Sumshift	summarizes and generates desired statistics relating to the results for the current crew and other input parameter values
Outshift	generates tables of output of current crew/ship/mission simulation
Change	steps values of the selected input parameter for the next simulation
Sumrun	summarizes the results of all simulations
Outrun	generates tabular or display output of all specified ship system simulations in the run

Output

Results of all processing would be made available to the analyst at a variety of optional levels of detail including:

1. each ship function
2. end of each ship/system simulation
3. end of a run of several ship/system simulations

Output would be available either at the terminal where the analyst submitted his input or, for local batch run requests, at the simulation computer center. The following indicates the types of results to be programmed:

- run/simulation identification information
- crew performance by ship subsystem function
- predicted technological levels by ship subsystem
- distribution of crew work/idle/sleep times by ship system function
- crew assignments and rate of utilization of personnel in crosstrained specialties
- areas of over/under manning

Average values per man per ship subsystem function and per hour would be displayed, together with pertinent ranges of values, maximum values, frequencies, and the like.

Consideration would also be given to the feasibility of automatic plotting either in a display or hard copy form of selected variable vs. time or vs. another variable. This is believed desirable when the number of simulations per run is a reasonable value.

The Linear Programming Model

Linear programming is essentially a standard technique for solving for the intensity of various activities such as maximization or minimization of an objective function, while satisfying certain constraining inequality conditions. In the present context, the objective function to be minimized, for example, might be cost and the constraining inequality conditions might be the level of manning of the various shipboard subsystems. The technique can be employed independently, but in the present application, it is probably best viewed as a subroutine embedded within one or several of the concepts previously described. For example, wherever in a model the requirements to assign crew members to ship subsystem functions occurs, there is the possibility of treating this as an optimizing problem and applying the technique of linear programming.

To set up a linear programming problem, it is necessary to specify:

1. a set of tasks or shipboard subsystem functions considered essential
2. a potential manpower supply of various capabilities and specialities from which the crew is to be chosen
3. some kind of cost parameters for each type of personnel. This provides a basis for preferring one manpower assignment over another when either assignment will satisfy all the requirements for accomplishing essential functions

We do not suggest assigning a cost in the usual monetary sense, but, at least initially, we suggest assigning a cost of unity to each individual man. The method will then solve the problem of finding the minimum number of crew members sufficient to accomplish all essential tasks represented in any given run of the model.

Concepts

As a simplified example to aid in the explanation of the concepts, consider Figure 9. Four essential functions are represented in the four columns. The vector

$$c = 100,\ 100,\ 100,\ 100$$

represents the requirement of 100 per cent completion of each of the four essential functions. The first row of the figure represents the information that one man of type 1 can accomplish 20 per cent of ship function 1 and 10 per cent of ship function 2 during any time period to be simulated. The second row represents the information that one man of type 2 can accomplish 50 per cent of ship function 1 and 5 per cent of ship function 2. Similar statements apply to rows 3 and 4 with appropriate numbers.

	Essential Ship Functions				
	1	2	3	4	Cost Per Man
Use men, type 1	20	10	0	0	1
Use men, type 2	50	5	0	0	1
Use men, type 3	0	0	25	50	1
Use men, type 4	10	10	10	10	1
c=	100	100	100	100	

Figure 9. Simplified example of minimum problem.

It is obvious that there are many feasible assignments of manpower that are sufficient to accomplish all essential ship functions.

Let w1, w2, w3, and w4 be the number of crew members of types 1, 2, 3, and 4 respectively. Then, the condition that all essential functions are adequately manned is expressed by the inequalities

$$\sum_{i=1}^{4} w_i A_{ij} \geq c_j \quad ; j = 1, \ldots, 4$$

where A_{ij} is the matrix of technological coefficients and the total cost (which is to be minimized) is

$$g = \sum_i w_i b_i$$

In this particular example, the minimum cost solution is to assign 10 men of type 4 and no other men.

The Technique of Linear Programming

Given a matrix A of technological coefficients, a column vector b of costs, and a row vector c of requirements, the problem is to find a vector w with components specifying the number of each type of personnel assigned to the crew such that the total cost

$$g = wb$$

will be a minimum, subject to

$$wA \geq c$$

$$w \geq 0$$

The standard method of solution is the simplex algorithm.

It is inherent in the mathematical structure of linear programming that, for every particular set of values of A, b, c in the minimization problem, there is also a dual problem which is a maximizing problem. Both problems are solved at one time by use of the simplex algorithm.

The Simplex Algorithm

There is a conventional matrix format for the simplex method called the simplex tableau. This is shown in Figure 10.

$$
\begin{array}{c|ccccc|ccccc|}
 & & \multicolumn{4}{c}{\text{A Labels}} & \multicolumn{4}{c}{\text{E Labels}} & \\
 & & A_1 & A_2 & \cdots & A_n & E_1 & E_2 & \cdots & E_m & \\
\cline{2-11}
 & E_1 & a_{11} & a_{12} & \cdots & a_{1n} & 1 & 0 & \cdots & 0 & b_1 \\
 & E_2 & a_{21} & a_{22} & \cdots & a_{2n} & 0 & 1 & \cdots & 0 & b_2 \\
\text{Row Labels} & \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots & & \vdots & \vdots \\
 & E_m & a_{m1} & a_{m2} & \cdots & a_{mn} & 0 & 0 & \cdots & 1 & b_m \\
\cline{2-11}
 & & -c_1 & -c_2 & \cdots & -c_n & 0 & 0 & \cdots & 0 & 0 \\
\cline{2-11}
\end{array}
$$

Figure 10. Initial simplex tableau.

Figure 10 is formed from the values of the A matrix, m rows and n columns; a set matrix, m rows and m columns; the column vector b of m rows; the row vector -c of n columns; and the remaining positions filled in with zeros.

The A labels and E labels are also conventionally used, and their proper manipulation is essential for the maximizing problem.

The method of solution consists of manipulation of the values of the tableau. Figure 11 describes the steps of the method. This flow chart is the natural preliminary to writing a computer program.

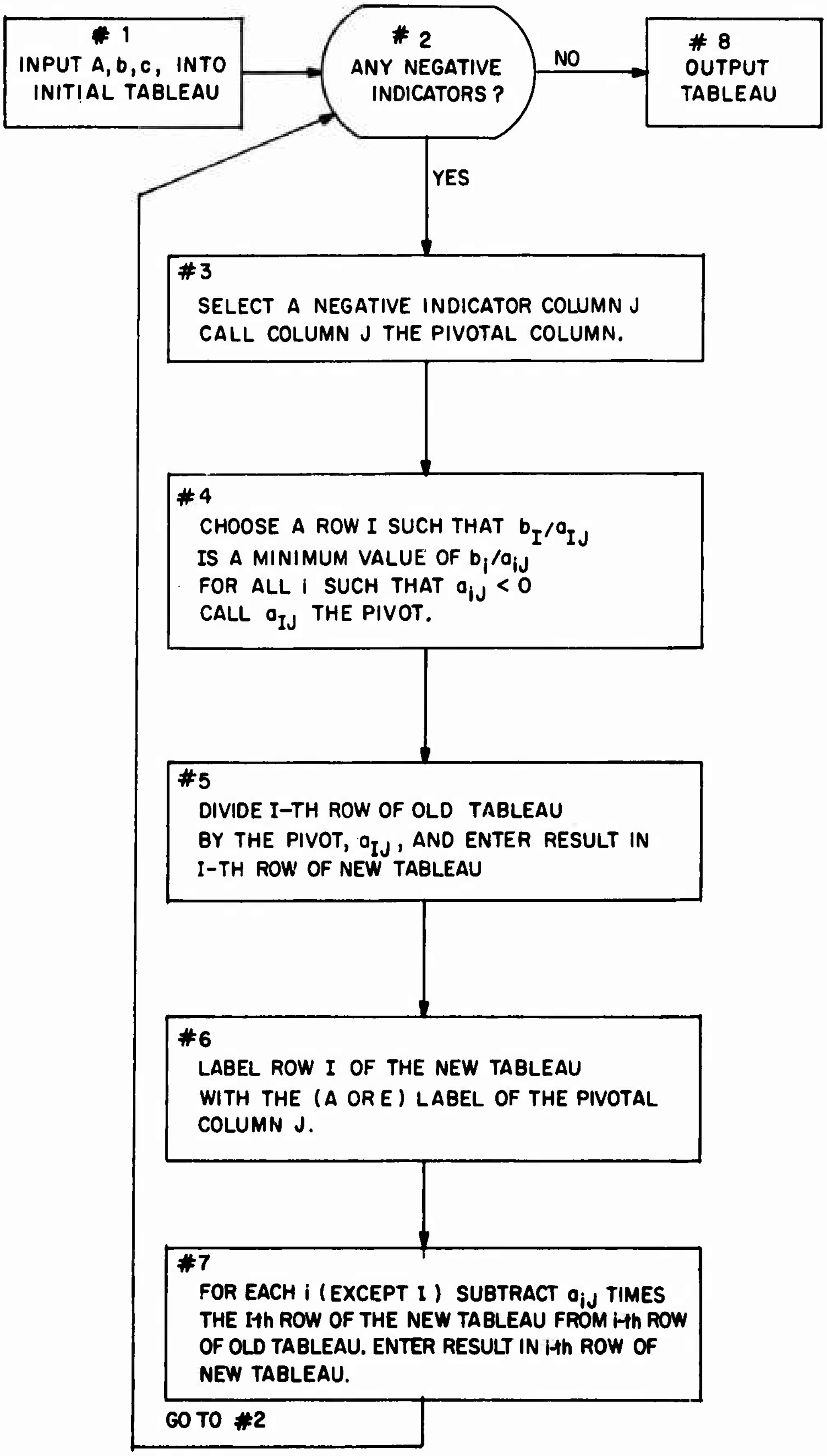


Figure 11. Steps in linear programming calculation.

The output tableau, Figure 12, contains the values to be interpreted as the solution of the problem.

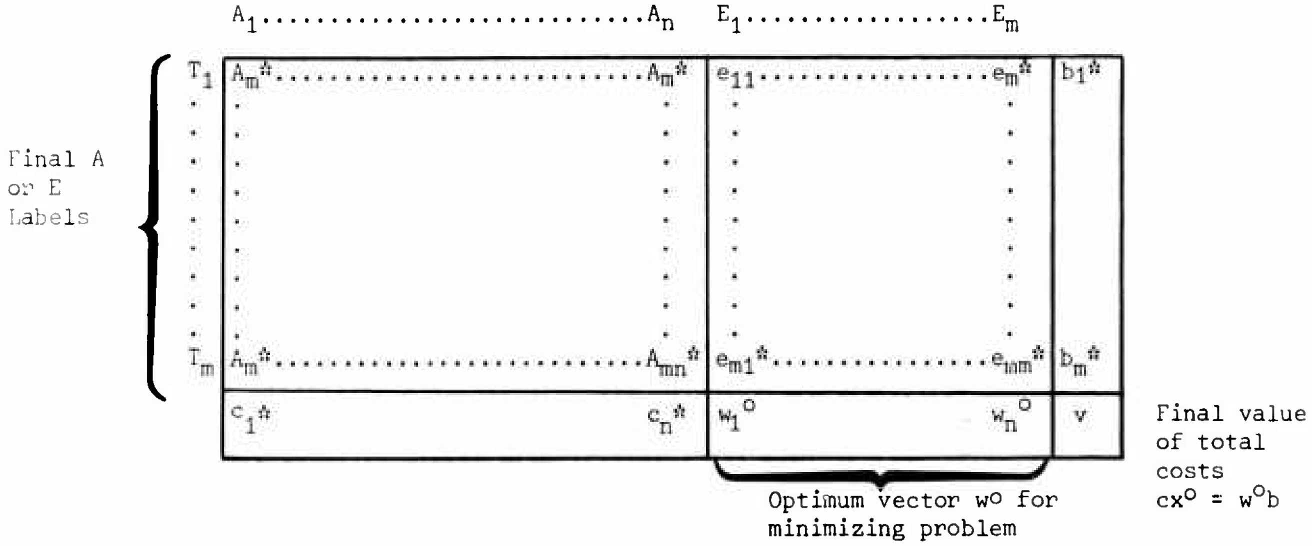


Figure 12. Interpretation of final tableau.

The results of interest in the present application are indicated in Figure 12 by w^o, which is the optimum number of crew member assignments and v, the total number of crew members assigned. These appear as the last row of Figure 12.

Accordingly, the stated optimization problem is carried through by linear programming and yields the crew assignment which is sufficient to accomplish all essential tasks with the minimum total number of crew members.

V. RECAPITULATION, DISCUSSION, AND CONCLUSIONS

The present report attempted to set into perspective trends in automation in Navy systems and stochastic computer simulation modeling approaches associated with modeling these trends from the point of view of predicting manning requirements in post year 2000 Navy ship systems. The extent and speed of projected automation was indicated to vary from ship subsystem function to ship subsystem function and from technology to technology. Fire control, radar, and propulsion were anticipated to be the most highly automated ship subsystem functions on the Navy ships of the post year 2000 era. These are also functions which are relatively high on automation at the present. The ship subsystem functions which were indicated to be lowest on automation during the time period under consideration were facilities maintenance, air support, and administration. It seemed quite reasonable to assume that stochastic digital simulation techniques could be employed to predict manning requirements for the automation condition on the ships of the post year 2000 era. There seems to be sufficient information available for deriving required input provided the predictive model is not made highly specific or dependent on the detailed simulation of individual events. Such a manning predictive model would resemble an economic system simulation model more than the customary man/machine simulation model.

There is another similarity between the forecasts of such a manning prediction model and economic system modeling. Specifically, the predictions of the manning model would represent forecasts over time as does the output of most economic models. These similarities to economic economic system modeling possess both advantages and disadvantages. The advantages revolve around the history of experience with such economic system models and the general acceptance of such of numerical predictive methods among the society in general and specifically with economists. One disadvantage lies in the problem of validating economic system models. Typically, economists have validated their predictive models through a historical method. That is, model output has been retrospectively compared with real data for a given time interval. However, such retrospective comparisons can only compare a model's forecasts with the actual course of action. Consequences and predictions of consequences of untaken courses of action cannot be compared. This type of validation parallels in logic that of a personnel selection system in which only selected candidates can be followed in terms of on-the-job success. Nothing can be said about those job applicants who are rejected but who would have been successful if accepted.

The problem of what constructs to build into an advanced simulation model weighs heavily when one considers the validity of a model. For example, policy considerations will probably weight heavily in the determination of whether and how fast the Navy can and will automate. Yet, none of the models considered in the present report included policy considerations. How does one validate a policy construct built into a model? Modelists have argued against the separate validation of the internal constructs included in a model. For example, Milton Friedman has argued that critics of methods of validation have missed the point by focusing on the internal constructs of a model. Friedman contended that the validity of a model rests not on its assumptions and constructs but on its ability to predict dependent variables.*

> The difficulty in the social sciences of getting new evidence for this class of phenomena and of judging its conformity with the implications of the hypothesis makes it tempting to suppose that other, more readily available, evidence is equally relevant to the validity of the hypothesis-to suppose that hypotheses have not only "implications" but also "assumptions" and that the conformity of these "assumptions" to "reality" is a test of the validity of the hypothesis different from or additional to the test by implications. This widely held view is fundamentally wrong and productive of much mischief. Far from providing an easier means for sifting valid from invalid hypotheses, it only confuses the issue, promotes misunderstanding about the significance of empirical evidence for economic theory, produces a misdirection of much intellectual effort devoted to the development of consensus on tentative hypotheses in positive economics [13, p. 14].

Discussion and Conclusions

Computer simulation, whether the equipment aspects or the man/equipment interactive aspects of an evolving system are considered, represents an established technique for providing decision makers with information which can form a basis for required decisions. Such modeling can provide information which is not otherwise available. As such, a model which can predict manning requirements in ships of the future could make a considerable contribution. Moreover, the full development of such a model seems to be within the current state of the art from the technical points of view. However, problems exist relative to the content and approach to such modeling as well as with how such models should be verified (validated).

Automation and technological change are certain in the Navy. From the manpower effects points of view, we must either come to grips with such problems or leave the effects to luck. Certainly, the latter course is foolhardy. Simulation represents one technique for approaching such problems. The present report described four computer simulation modeling approaches which might possess potential for achieving the desired end result. We do not hold that any one of these approaches will achieve the desired end result by itself. Other approaches are possible and, in

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* Friedman, M. *Essays in positive economics.* Chicago: University of Chicago Press, 1953.

fact, other approaches were developed during the course of the present work. We do not support one of the described approaches over another. Rather, we tend to believe that a symphonic orchestration of two or three of the separate approaches would produce a usable tool. Would the tool produce forecasts which are always "eventually certain"? Probably not. Would the simulation model produce dependent variable indications which are "currently probable"? Probably so. Prior results with other computer simulation models both in the man/machine interactive sphere and in other areas tend to support this point of view. As few as 15 years ago, it was held that simulation of the human component in a man/machine system was impossible, impractical, and nondefensible. Yet, in recent years, the feasibility and utility of such human-equipment performance interactive modeling have been demonstrated in a wide variety of applications. Siegel and Wolf (1969) describe a number of such applications and developments. Accordingly, it seems that while the development of a model which possesses the general purpose of predicting the manning requirements of post year 2000 ships is not without risk, such a development is desirable and possible.

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