

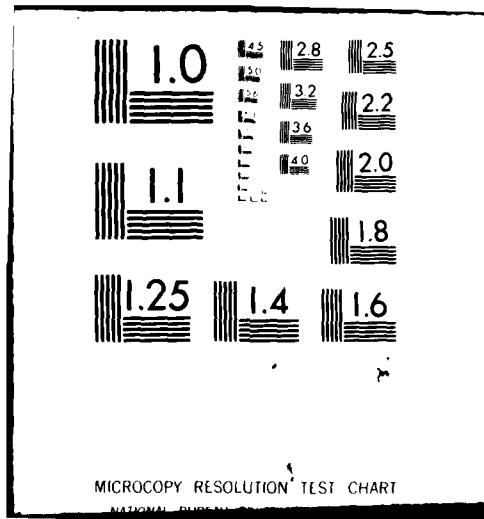
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SURVEY AND ASSESSMENT OF MODELS OR DECISION RULES DETERMINING S-ETC(U)
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SURVEY AND ASSESSMENT OF MODELS
OR DECISION RULES DETERMINING SPARE
PART LEVELS FOR NAVY ELECTRONICS EQUIPMENTS.

Prepared for
Naval Electronics Systems Command
Headquarters
Washington, D. C.

Contract Number
N00039-79-C-0187

Approved

H. A. Krivka
Vice President
Ship Systems Branch

7 September 1979

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Section I

Introduction

The primary objective of sparing procedures as applicable to the task assignment is to maintain an acceptable level of spare parts input into a system while keeping within prescribed boundaries of cost. The aforementioned objective, simple as a goal, assumes a greater complexity with the imposition of conditions and restrictions.

For this task there is the necessity to comply with the Navy's supply procedures for spare parts. This requires as a minimum, abiding by the requirements set up for items or components that are classified as critical, demand and insurance items. Maintenance policy such as repairability at the source must be considered in addition to the possibility of other constraints such as weight and cube. Stocking at various levels of supply (ship, mobile support forces and depot), and compliance with mission time and mission function have to be considered.

The function of the sparing models or methodologies for electronic equipments for this task should have the following criteria:

1. compliance with the Navy's supply procedures
2. maintaining levels of spare parts
3. abiding by cost constraints
4. administrative ease.

Methodologies for spare part procedures are abundant. However, they span the spectrum of the area of logistics ranging from those that are all encompassing to those that apply to specific areas. It will be necessary to separate the methods that are applicable to this task from those that are not.

It should be emphasized that it is not so much a case of new sparing models or methodologies that are needed as the application of those that exist. However, the existing models often have to be adapted to the criteria or goals that are specified.

Section II

Task Statement

~~The task for Contract N00039-79-C-0187~~ requires a survey and assessment of models or decision rules applicable to the determination of spare parts levels for Navy electronic equipment be made. This survey agreed to include a search of pertinent literature published subsequent to 1 January 1974, together with such other sources deemed appropriate by contractor to establish a list of available sparing models.

Models are to be evaluated and ranked according to criteria to be jointly determined by procuring activity and contractor.

A report is to be furnished, in ten (10) copies, detailing:

1. Those models determined to be appropriate for use, listed in order of desirability
2. The criteria used to evaluate and rank the models,
3. Copies of descriptive material on the top ten ranked models,
4. List of sources investigated.

↓ The models determined to be appropriate for use, listed in order of desirability are contained in Section VI. The criteria for evaluating and ranking applicable models are contained in Section III (Area of Task). Copies of descriptive material on the top ten ranked models are listed in Appendix A and the list of sources are listed in the Bibliography and Literature Evaluation Form A.

Section III

Scope of Effort

Area of Logistics

This task falls into the broad area of logistics. In order to gain a perspective of the task in relation to the area of logistics, it would be feasible to specify some of these areas.

The following are functions associated with the process of logistics:

1. budget decisions
2. procurement
3. acquisition
4. distribution
5. maintenance
6. management.

These functions are interrelated and compounded by problems such as modes of transportation, facilities, man power, duplication, supply level, economical management, producibility, performance, centralization, and safety.

The area of logistics is broad and multifaceted while the task assignment is limited in scope. In order to cope with the task assignment, the area of logistics will be arbitrarily partitioned by a procedure depicted under Approach (Section IV) in order to classify models and eliminate those that do not pertain to the task assignment.

Area of Task

Provisioning, excluding the various facets of spare management such as storage, transportation, and reordering policies, reduces to providing adequate levels of spare parts at reasonable cost. Therefore, the sparing procedure should take into consideration

1. provisioning effectiveness
2. cost evaluation (weight and cube could be considered).

The methodologies or model required to achieve the above ends could be done by hand, the use of tables, or computerized calculations

or combination of these procedures. Additionally, the model must be capable of complying with the Navy's supply procedures, that is; the model should be capable of providing for the requirements of criticality, demand insurance items, and infrequently used items. The model should be mission oriented while abiding by a normal usage concept. The model should be what is called a static in contrast to a dynamic one, that is; the time interval under consideration within the model would not be partitioned and the methodologies for the time intervals would not change. In addition, it would be feasible to have spare support at three levels:

1. organizational level of supply -- spares carried aboard ship or at the equipment site
2. intermediate level of resupply -- spares carried aboard the mobile logistics support force and selected shore activity
3. depot -- spares located at the depot.

Section IV

Approach

The approach to the task involved a review of literature sources to determine whether the material was applicable. In order to accomplish this, it had to be determined what kind of models were being considered, the scope of the models and whether they were applicable to the task. This was accomplished through the use of three forms which subsequently will be described.

Initially, the breakdown of the approach to the logistics problem can be categorized as follows:

1. stochastic (probabilistic, statistical)
2. deterministic (algorithms, mathematical)
3. empirical (rule of thumb, historically practical).

Many models have features of more than one of the above categories. The one that is most pertinent will be the one under which the approach will be classified. Essentially, the task would be concerned with the stochastic approach in that, in general, uncertainty underlies the sparing process. The stochastic procedures involved would depend upon underlying processes and assumed distributions. For provisioning models input distributions could be exponential, negative binomial, Poisson, Weibull, or possibly some other type. Feasible deterministic procedures will be reviewed as well as empirical procedures.

The problems of logistics for this task can be broken down into five general areas:

1. forecasting
2. inventory control and procurement procedures
3. distribution
4. maintainability
5. availability

Not considered are areas such as producibility, safety and technical performance.

The area of forecasting generally involves stochastic processes and procedures and would have a bearing on the other four above mentioned

areas. The stochastic procedures would depend upon the distribution of the underlying random variable such as the Poisson, normal and negative binomial distribution. Algorithms or procedures that constitute methodologies would fall in this area.

The areas of inventory control and procurement procedures which encompass management budget decisions and acquisition are embedded in the economics of ordering quantities of items. The approaches or methodologies depict various processes which are classified as: queuing models or systems, game theory, optimality theory, operations research, and markov processes (see References in bibliography).

The area of distribution would involve problems such as transporting, lead times for ordering and location of distribution points. Methodologies concerned with such problems are linear programming, network theory, dynamic programming and various specialized algorithms.

The area of maintainability would involve the determination of type, quantity, and extent of maintenance which must be incorporated in the logistics system as well as factors such as manpower, test equipment and technical support. Basically, a system is considered maintainable within allowable time and personnel skills. The objective is to keep the system in operational condition. There are many papers in the literature concerning the multitude of problems involved in the area of maintainability. Analytic methods could be in the areas of renewal theory, operations research or the Bayesian approach.

The area of availability involves the satisfactory operation in time of equipment(s)/system(s) when used under state conditions. Involved in this concept are operating time, active repair time, administrative time and logistic time. Provisioning effectiveness contributes to availability.

The five areas depicted above represent a general breakdown of the logistic process. Some of the methodologies described under these areas could and do span more than one area and in some cases serve as

models for an entire logistic system. It is not necessary or desirable to get involved in the various aspects and details of the methods that are applicable to the problems of logistics. The purpose is to layout the framework of logistics into which the task statement under consideration could fall.

In order to classify the material which comes under review, three forms for literature review have been developed (see Forms A, B, and C, pages IV-5 through IV-7):

1. Form A -- This form provides for the listing of the (a) literature sources investigated, (b) whether the material is applicable to the task, (c) the three types of analysis depicted above (stochastic, deterministic and empirical), and (d) the five general categories depicted under areas of logistics above.
2. Form B -- This form is more detailed and supplementary to form A. Listed is a description of the purpose, background, model, inputs and outputs, as well as comments concerning the literature source.
3. Form C -- This form is a supplement to forms A and B. It lists the literature sources that are appropriate to the task assignment. It describes the provisioning model, the mode of calculation (hand, tables, computer), details the kinds of inputs and outputs.

If the literature source material does not fit the requirements of the task statement, in general, only form A will be completed. If the literature source investigated meets the requirements of the task statement or partially meets the requirements, the material will be reviewed further and the results will be summarized according to the layout of form B. If the literature source has an applicable model, it will be listed on form C. Form C as well as forms A and B are used to describe and evaluate models that are found applicable to the task statement.

The approach to the task would be to review the literature sources based upon the above procedures and to classify the reviewed logistics models as follows:

1. not part of the task assignment
2. part of the task assignment
3. related to the task assignment.

The feasibility of following such an approach would be that areas not germane to the task assignment can readily be eliminated while those that are pertinent can be reviewed in detail.

TITLE

FORECASTING

COMMENTS							
STOCHASTIC	DETERMINISTIC	EMPIRICAL					
INVENTORY CONTROL	DISTRIBUTION	MAINTAINABILITY	AVAILABILITY				

FORM A

Subject:

Literature Source:

Purpose:

Background:

Model:

Input:

Output:

Comments:

[illegible]

Section V
Description and Evaluation of
Applicable Models

Kinds of Models

Numerous abstracts were examined for source material (see bibliography for material reviewed). There were over 125 articles that appeared to be related to the task assignment that were procured through the abstracts, only 74 articles were found to be pertinent. The number that were found to be most related to the assignment was approximately 20. In addition, several texts were reviewed that contributed to the general concepts that are incorporated in this report.

Most of the methodologies that were found applied to the areas of inventory control, procurement procedures, distribution and maintenance. Many of the approaches were economic models which emphasized cost minimization in the areas of ordering, procurement, shipping, holding and shortages. Other models were time oriented with emphasis being placed upon resupply time, ordering times, and lead times and associated with some of these times were various echelons of supply (i.e., ship, tender, depot) and stocking levels. Still other models provide solutions to specific types of problems such as shelf life deterioration, cannibalization and handling parts that have demand rates over one (1) year.

The models that relate to the requirements as specified in the Scope of Effort of Section III are listed below. The models incorporated probabilistic functions, namely; the normal, negative binomial, compound Poisson, and the Poisson:

<u>Probabilistic Function</u>	<u>Title Number (Form A)</u>
Navy Model (normal and Poisson)	
Current (FMSO, OPNAV 4441.12A, APL, FLSIP)	9, 40, 15, 61
Proposed (Tender)	10
Proposed (Low Usage Items)	14

<u>Probabilistic Function</u>	<u>Title Number (Form A)</u>
Normal	13, 30, 32, 60
Negative Binomial	36, 37, 38
Poisson (Compound)	8
Poisson (Monte Carlo)	31
Poisson	20, 26, 18, 7, 11

Scope of Models

The evaluation of the applicable models must be done in terms of criteria of this task. Under Scope of Effort in Section III, the criteria for a model would be:

1. provisioning effectiveness
2. cost evaluation (cube and weight should be considered)
3. compliance with the Navy's supply procedures
4. provisioning at three levels of supply:
 - a. organizational (equipment/system or ship)
 - b. intermediate (mobile logistics support force or tender)
 - c. depot.

The selected models will be matched against the above criteria and evaluated in terms of whether they meet the criteria, and if not, what the shortcomings are.

Navy Models (current and proposed)

The first probabilistic model to be evaluated, as depicted in Section V under Kinds of Models, will be the Navy Models (current and proposed). The current FMSO model is simple: If the average demand rate for a part application ($\bar{D}_{RP}$) for a three (3) month period (based essentially on historical data) exceeds or equals 1, the applicable model will be based on the normal function. If the demand rate ($\bar{D}_{RP}$) is less than 1, the applicable model will be based on the Poisson function. Sparing for parts is based upon the formula:

$$\bar{D}_{RP} + t_p \sigma_p$$

where t_p is a risk factor and σ_p is the standard deviation of the part type. The t_p factor (risk factor) takes into consideration many elements, such as item cost, requisition sizes and demand for items. In addition, an effectiveness goal concept based on satisfied and unsatisfied load list requisitions is used to adjust the t_p factor for costs of overstocking or understocking stock levels. Also, the concept of criticality can be applied through the t_p factor. Judgment and budget constraints could work through the criticality concept to add or take away from the t_p factor that would ultimately affect stock levels. The same procedure is used when applying the Poisson model, except that a table lookup procedure could be used. The Navy uses the model for submarines and tenders.

According to OPNAV 4441.12A (title 40) and the allowance parts list (APL) (title 15) the basic resupply procedures are dependent upon the following classification of items:

1. demand based items -- those used aboard ship at least once during a 90 day period, has a .90 probability of filling total demand for these items over the entire operating period
2. insurance items -- those which have a demand of .25 or greater usage in 1 year but less than a demand base item will be selected only if essential to the support of equipment considered vital to the ship's mission
3. long life item -- those having a demand .25 or less in one year
4. technical override items -- those used to support a newly deployed equipment
5. military essentiality code (MEC) items -- currently there are two classifications for these items - critical and non-critical with most items being classified as critical (over 90%)
6. best replacement factor -- incorporated in the current Navy procedure, it is the basis for the calculations of the above items and is defined as: A weighted average which takes into consideration recent demand data, older demand data and the initial technical estimate of usage.

The OPNAV 4441.12A and the APL procedure are incorporated into the FLSIP (fleet logistics support improvement program) and are used for provisioning purposes. The procedure is depicted in title number 61 and is used for all Navy provisioning (other than that for submarines and tenders).

Referring to Table I, Navy model titles 9 (FMSO) and 61 (FLSIP) it will be noted that provisioning effectiveness and evaluation of cost, weight and cube are not considered in the current procedure. The provisioning effectiveness and cost constraints are approached indirectly through the risk factor (t_p) and gross and net effectiveness (for definitions of gross and net effectiveness see the Glossary). Without an effective methodology for determining the depth and range of parts as they relate to equipment/system, stockage of parts will be a unresolved problem. In other words, as depicted in the FMSO and FLSIP models, stockage is not based on a model which simulates the equipment/system but rather utilizes a per unit or part demand base.

Title 61 is a procedure used for computations of FLSIP COSALS. This procedure is rooted in OPNAV 4441.12A (title 40) and the APL (title 15). The Poisson function is used for depth computations for items to be provisioned.

Title number 15 is not a model. It merely describes the procedures used by the Navy for stocking shipboard parts. It is a reference for the provisioning and supply procedures and requirements for the Navy.

Title 10 is a proposal for stocking at the tender level. The purpose was to develop tables for provisioning technicians that would be easy to use. The tables were designed to allow for purchase of low cost items by provisioning technicians that are limited to \$100.00.

Title 14 is a proposed procedure for sparing long life parts. This procedure would allow for long life items (those that have a demand rate that is less than insurance items) to be spared for a hull or tender. The current Navy model makes no provision for sparing items with low demand rates. The proposed method of title 14 would allow for the sparing of such items within certain cost constraints.

TABLE 1
CRITERIA FOR MODELS

<u>Model</u>	<u>Title Number</u>	<u>Provisioning Effectiveness</u>	<u>Minimization</u>		<u>Navy Procedures And Essentiality Codes</u>	<u>Provisioning Level</u>			
			<u>Cost</u>	<u>Weight</u>		<u>Equipment</u>	<u>Tender</u>	<u>Depot</u>	<u>Hull</u>
Navy (Poisson and Normal) Current	9 FMSO		X		X	X	X	X	X
	40				X	X	X	X	X
	61 } FLSIP				X	X	X	X	X
	15				X				
	10				X				
Proposed	14					X	X	X	
Normal	13	X				X			
	30	X	X						
	32		X	X					X
	60	X				X	*	*	X
Negative Binomial	36,37,38		X	X	X	*	*	*	X
Compound Poisson	8					X			
Monte Carlo - Poisson	31	X	X			X			
Poisson	20	X	X			X			
	26	X	X			X			
	18					X			
	7	X	X			X			
	11	X	X	X		X	X	X	*

*Adaptable to this Criteria

The shortcomings of the Navy models (FMSO and FLSIP) are:

1. The provisioning effectiveness concept is not in either model. Indirectly the gross and net effectiveness concept contribute to a kind of provisioning effectiveness. The Navy's models are parts oriented (probabilities for depth only are assigned) rather than for equipment/system. If a model (stochastic) were used for provisioning on an equipment/system basis that incorporated the interaction of both range and depth for provisioning a probabilistic measure call provisioning effectiveness would be obtained.

The reliance upon historical data, as is being pursued currently by the Navy is adequate provided that the units do not change appreciably in failure characteristics and demand is relatively constant over time. However, for electronic equipments and new equipments where the demand history for items could and likely would be inadequate for provisioning the over-all equipment/system approach is feasible.

2. The t_p factor in the FMSO model provides for cost evaluation through penalty factors for overstocking and understocking. However, the estimate for such penalty factors are subjective and the approach moves towards an emphasis on budget constraints. The model is geared to a cost effectiveness model rather than a mission effectiveness model.

3. The current models (FMSO and FLSIP) have no overall evaluation standard. Unless provisioning is measured in terms of mission effectiveness or a similar mode, the current approach will be open to question. The problem synthesizes to one of: Will cost effectiveness take priority over mission effectiveness or will cost effectiveness be a subset of mission effectiveness?

4. The military essentiality code (MEC) for FLSIP has two classifications (critical and non-critical). It appears that most items are classified as critical (over 90%). With this approach a viable procedure does not exist for provisioning for the range of items.

5. In effect FLSIP employs a Poisson function for determining part depth where the following equation is used:

$$\text{ALLOWANCE ITEM} = \text{MEAN (ITEM)} + 1.28 \cdot \text{MEAN (ITEM)}$$

For a COSAL this procedure for calculating depth parts is oversimplified.

Normal Models

There is a kind of evolution in the development of the normal model starting with title number 13 through 30, 32, and 60. The original concept was developed in title number 13. The approach was based on the central limit theorem with an assigned provisioning probability goal. Title number 30 expanded the concept of title number 13 to include the equipment/system availability. The author of title number 30 amplified and clarified approaches that were incorporated in title 13. Title 32 indicated a methodology not fully developed according to the author, for stocking a hull with constraints of cost, weight and cube.

The author of title 60 tested the model of title 13 and 32 above using a computer. Basically what was found was that the results were erratic. Certain distributions were skewed with the result that stocking was mostly too high. If the number of components (or processes per system as they are called) increased and if the operating time increased, then there was an improvement in results.

A weakness in the approach that seemed to be ignored was the basic central limit theorem concept, that is; the density function of a sum of independent random variables approach the normal density function regardless of the type of density function each of the variables had. The word random refers to the samples that would make up the resultant normal density function. These samples must be selected uniformly from the various distributions to generate a resultant normal distribution. Invariably, this is not the case. Each part that fails represents

a part from a density function. There are as many density functions as part types (assuming that the process that produces these parts are in a state of statistical control) and the frequency of failure for part types are different. As a result, adherence to the central limit theorem is not achieved. In addition, the theorem upon which this approach is based states that the independent random variables must be sufficiently large (whatever large means) and that approximate normality will result. In the examples of title number 60, for small systems where the sample numbers were small, the weakness of the approach was borne out, the prediction for spare parts was poor.

The authors of the approach ignore the practical aspects of the technique in that the random concept seems difficult to handle, especially for small systems where the results are unreliable. What would be needed would be either a weighting technique to overcome the random problems or using a procedure that relies upon the distribution of sample means. Regardless, at this point in time, the following problems with the concept are evident:

1. it is unreliable for small equipments
2. a procedure must be developed to cope with the concept of randomness
3. the approach requires that the process generating the parts be statistically stable
4. the methodologies in the various write ups (title numbers 13, 30, 32, 60) would have to be merged to meet the requirements of the task
5. the approach would, for practical purposes, have to be computerized
6. a test procedure would have to be employed in order to determine whether the assumptions of normality is violated and if so, what procedure should subsequently be followed.

Negative Binomial Model

Title numbers 36, 37 and 38 concern the POLARIS logistics model. It is a cost oriented model for a hull. Actually, it is called a

loss minimization model. Included in the model are penalty factors for overstocking and understocking as well as scaling or weighting factors similar to the t factor for the Navy's FMSO model (title number 9). The procedure is based upon demand data and is oriented to mission times of 2 to 3 months. Utilizing a coefficient of variation (in this case ratio of the sample mean to the sample variance) for part types the negative binomial distributions approximates the Poisson for values less than or equal to .75, the exponential for values equal to 1 and the normal and gamma for values greater than 1. The coefficient of variation in effect is a hazard rate which in essence allows for approximating the Weibull distribution. The model can be applied to new parts that belong to a certain class, without any demand history of these new parts and it can be applied to cases for low demand items.

A minimization procedure for cube, for example, requires a demand rate, the associated standard deviations and the associated holding and shortage cost ratios. The procedure requires having the allowance list of components in a priority sequence of nondecreasing essentiality (defined in a subsequent paragraph) in order to calculate a minimum cube. The process is an iterative one for approximating the total cube required. Adjustments would have to be made in assigned weighting factors for shortage and holding costs to derive a total cube that meets specified requirements. The entire allowance list would be determined by iteration through individual minimization of loss function (overstocking and understockage). A computerized approach would be required for this model because of the volume of components involved.

A military essentiality code for items had been developed. A rating procedure was proposed ordering parts in importance to system mission. This was done in terms of probability values for 27 categories of items.

The model is cost oriented with built-in overstocking and understocking penalties. It is a component oriented model based upon the negative binomial distribution just as the FMSO model is based upon the Poisson and normal distributions.

The shortcomings that apply to this model are:

1. Much subjective judgement can be injected into the model when determining penalty cost values for overstocking and understocking. The analysis of cost losses from overstocking and understocking can vary substantially, dependent upon the interpretation of contributing factors to such losses.
2. A question arises concerning how cost minimization relates to mission success. Indirectly, if cost minimization worked properly more funds would be available for provisioning. However, there is no provision in the model, except indirectly for measures of mission success.
3. Currently, items are precluded from being provisioned, especially when demand for them is low. The fact that certain items are not provisioned on one mission does not mean that they should not be provisioned on subsequent missions. No solution for this condition exists in the model. The claim is made that low demands could be provisioned but no perceivable procedure is described.
4. The scale values (weighting factors), like the t_p value for the FMSO model, serve as a dumping ground for unresolved factors. It serves much like a cranking device to increase or decrease spares in an endeavor to match demand. How well the procedure works has yet to be resolved.
5. The series concept for provisioning especially in relation to electronic equipments is not considered for range and depth of spare parts. For example, assume demands for parts are independent and the sparing procedure calls for the provisioning of parts for a three month mission with a probability of .90. If, for illustrative purposes, there were eight part types that were vital to the mission then the probability of not having sufficient vital spares would be $(.90)^8$

or .43. With an increase in the number of vital parts, it can be seen that mission success deteriorates rapidly without an adequate range and depth of spare parts.

6. The model is a cost oriented model and demand oriented model designed for provisioning a hull. It is not mission oriented and not well suited to meet the criteria of provisioning electronic equipments.

Poisson Model

Title number 8 was cited to illustrate the use of a compound Poisson function for spare provisioning. The concept of spare shelf life deterioration as well as bunch effects (where a part in an equipment fails, other parts are replaced, as well as the failed part, for maintenance and other purposes) has a bearing upon the spare distribution functions. A mode of representation would be a two parameter Poisson function (called a compound Poisson function) in lieu of the single parameter Poisson function.

Title number 31 illustrates the adaptability of the Black and Proschan model for system design. A Monte Carlo procedure is used to simulate random equipment failures. The equipment is simulated by a computer program based upon a series parallel configuration. As operating time increases, failures are simulated through the random generator to determine if the equipment/system would fail. Down times are cumulated as operating times increase in order to calculate the system availability. The equipment/system simulation in the series parallel configuration has the fault tree analysis characteristics (various modes of system failure such as one, two and three components). It is conceivable that the fault tree analytic approach could be a substitute for the Monte Carlo procedure. However, by the procedure described, the equipment/system can be analyzed for design (or redesign) purposes or for provisioning purposes.

Title number 20 is a spare part procedure for new equipments. It is a hand solution model. Given the components costs, the number of like components, operating time and the failure rate for the components,

assuming an exponential process and the adequacy of spares as having a Poisson distribution, a model is developed. The model was designed for equipments with a small number of components and sparing is based only on critical items. A provisioning goal is set and based upon a series configuration of parts and exponential process, spares are added until a provisioning goal has been met. In conjunction with these computations, a cumulative cost value is derived.

Title number 26 is an expanded version of 20 above that was written by the same author. A more detailed account is given in this paper concerning the proposed methodology. It was emphasized that the procedure does not rely upon an exponential process, in other words; it can be designed for a normal, negative-binomial or Weibull processes.

Title number 18 is concerned with the Poisson model on a per part basis. A computer program has been written to generate output at various confidence levels (i.e., .80, .90, .95). Based upon a multitude of computer runs, charts have been drawn to determine the number of required spares dependent on the confidence level desired. The procedure does not consider provisioning effectiveness.

Title number 7 is a modified Black and Proschan optimum spare provisioning model for equipments/system. The claim is made that after exhaustive evaluation of the state of the art; the model (Black and Proschan) is the most capable of providing the support and trade off orientation required in the world of provisioning.

The methodology was computerized with some slight changes in the model. The computer program was first written in FORTRAN IV for the Honeywell 2200 for 900 line items. Subsequently, the model was programmed to run on the UNIVAC U-494 and it was capable of handling 7,000 line items. Then, the Naval Applied Science Laboratories at Brooklyn, New York, estimated that it would be possible to handle 30,000 line items on the CDC-6600 with running time over 3 hours.

The paper identified equipment for which usage data was collected over a 1½ to two year period for various equipments. Two tables,

a comparison was made between the conventional Navy procedures and the Black and Prochan model for provisioning results. The comparison was very favorable for the Black and Prochan model.

Title number 11 is a modified Black and Prochan model for equipment(s)/system(s), tender(s) and depot(s). It is an expansion of the Black and Prochan model beyond the equipment/system level. It is a computerized system in the FORTRAN IV language and written for the 7090 computer. It handles up to 2500 line items and can easily be adjusted to handle 8,000 or more. The model was designed to provide a provisioning procedure for the AN/SPS-40 radar at the equipment (ship) tender and depot levels. Over 12,000 part application and over 2,000 distinctive parts were involved. The input was the FSN or part number, cube, weight, cost, number of applications, replacement rates and resupply procedures.

The program has the capability to set provisioning goals at prescribed levels for equipments/systems, tender(s) and depot(s), and cumulative cost, weight, and cube and a normalized provisioning reliability function. There are options in the computer program which allow for checks and verifications of computerized results. The provisioning probability calculations for the stock list of this model in contrast to the standard stock list for the APL was extremely favorable.

The shortcomings that apply to all of the Poisson models are:

1. The models must be adjusted to accomodate a multi-mission provisioning procedure. The Black and Prochan model is an initial type provisioning model. To accomodate for follow-on provisioning in certain cases, a modification in procedures may be required. This would be true especially when the complete range of on site parts was not provisioned during initial provisioning using this model.
2. The models are restricted to part replacements being distributed as a Poisson function. The models could be more general, certain failures for parts could be normal, compound Poisson, negative binomial or Weibull. Accomodations for such functions do not

exist in the models.

3. System availability calculations are not in any of the models.

Section VI

Rank of Applicable Models

Based upon the Scope of Effort for the task (Section III) and Description and Evaluation of Applicable Models (Section V), it is evident that there are shortcomings in all models that were found.

The reviewed models were designed for specific purposes. Some were designed for sparing a hull, others were designed to be simple to understand and apply, others were designed for table lookup or to be hand calculated, others were designed for sparing at the equipment/system level and others were designed to comply with budget constraints.

The purpose of the effort of this task was to find sparing models for electronic equipment(s). This would tend to restrict the problem to the area of low demand rate items. Low demand rate items, as far as provisioning is concerned, usually are depicted in terms of a Poisson function. Other functions, such as the compound Poisson, normal and negative binomial may apply. The above functions were found in selected models but the model designs did not completely meet the scope of the task for models as described in Section III.

The selected models have been ranked based on the criteria of factors described in Section III (Area of Task). Provisioning effectiveness was considered the primary factor in ranking models in that a mission could be seriously affected due to the lack of parts. The use of a model which employs the provisioning effectiveness concept affords a measure whereby a missions success can be gauged for equipment(s)/system(s). Cost (as well as weight and cube) of parts was considered secondary in importance. A model with a cost (weight or cube) limiting feature that lacks provisioning effectiveness lacks dependability. Regardless of the model that is employed for provisioning, it is necessary to comply with the Navy's supply procedures. In effect, unless these procedures constitute a major problem for a provisioning model, they would not be considered significant. Provisioning for tender(s) or depot(s) is considered secondary to equipment(s) provisioning. If a model has this capability in addition to equipment(s)/system(s) provisioning capability, all else being equivalent, the model would be

considered a superior model. Table I (Criteria for Models) depicts the criteria as applied to the models that were considered applicable for consideration. The ranking of the models are as follows:

1. Title number 11 (Poisson-Computerized)
2. Title number 7 (Poisson-Computerized)
3. Title number 31 (Poisson-Computerized)
4. Title numbers 20, 26 (Poisson-hand calculation)
5. Title numbers 36, 37, 38 (negative binomial-POLARIS model)
6. Title number 9 (FMSO model)
7. Title numbers 40, 15, 61 (FLSIP model)
8. Title number 60 (normal model-needs further development)
9. Title numbers 13, 30 (normal model-hand calculation)
10. Title number 13 (normal-hand calculation).

Title number 11 comes closest to meeting the requirement for the scope of effort for a model. It provides for provisioning effectiveness, calculations for cost, weight, cube, provisioning at three levels of supply and accomodates the Navy's supply procedures. However, it does not encompass multi-missions. Based on the provisioning goal assigned certain parts may not be provisioned on the first mission, especially for highly reliable equipments. On subsequent missions a procedure has to be set up to cope with this situation.

Title number 7 is similar to number 11, in that it needs to be multi-mission oriented. A major difference is that it is limited to the equipment level. There were no indications of calculations for weight or cube but apparently that would not be a problem. However, the provisions for the Navy's supply procedures may require a certain amount of computer program adjustments.

Title number 31 is a procedure to improve system design for the purpose of enhancing reliability. The purposes is to detect reliability weakness in an equipment/system. The procedure employs the Black and Proschan model with the Monte Carlo feature for simulating failures. It is a computerized model, requiring a simulation of a system (in terms of fault tree analysis, where a system is laid out in series and parallel configuration) for analysis. However, the range of the model is limited to small system. Although the model was designed as a tool for enhancing

the reliability of an equipment, it is adaptable as a provisioning tool.

Title number 20 and 26 are hand models that are suited for small equipments.

The POLARIS model is preferred over the current Navy's procedure in that it is more flexible. The provisioning procedure for parts for the POLARIS model are refined through the use of the coefficient of variation and the military essentiality ratings. The POLARIS model is budget oriented and provisioning is geared in that direction rather than upon mission success. The procedures for POLARIS and FMSO are not that much different conceptually, except that FMSO relies upon the normal and Poisson functions for provisioning whereas the POLARIS model relies upon the negative binomial function.

The FMSO model through the use of weighting factors (assigned through the t value) give this model a depth of provisioning capability not possessed by the procedures of FLSIP COSALS (based upon OPNAV 4441.12A and the APL). Under the net effectiveness procedure for a COSAL for both models a kind of mission effectiveness is achieved (the net effectiveness is the demand satisfied divided by the demand received of requisitions for load list items).

Title number 60 has shortcomings which are listed under normal Model in Section V. These shortcomings apply to the underlying concept for all title numbers in this group (13, 30, and 60). This, in addition to the difficulty in administering and interpreting results is cause for not recommending the methodology.

Section VII

Conclusions and Recommendations

No model was found that would be general enough to meet the complete requirements for provisioning for electronic equipments/systems. Models that have favorable features have been found but no comprehensive model was found. The most applicable models that are available are those described under Poisson models. To meet the needs of a general and more complete model, the following modifications should be incorporated:

1. Provide for provisioning based upon the multi-mission concept. The sparing procedure for this concept should take into consideration long life items and those items that are not spared on previous missions. The multi-mission concept is not incorporated in the Black and Proschan model, under certain conditions, provisioning could be seriously affected, if the model was used for restocking.
2. Provide for a Monte Carlo procedure to circumvent the initial provisioning restriction of the Black and Proschan model. Component failures could be simulated for an exponential, normal or other type of combination of processes for spare parts provisioning.
3. Using the coefficient of variation (the ratio of the mean to the variance) for a test for unit provisioning. This would expand the capability of the model so that parts could be provisioned based upon the Poisson, normal or other distributions.
4. In order to provide for a bunched effect where the replacement of one unit leads to the inspection of other units and possible replacement, a compound Poisson distribution for parts replacement should be used. A procedure for estimating parts that are subject to such replacement should be set up and identified so that the information can be incorporated in the model.

5. A procedure should be incorporated to allow for the provisioning of long life items. This could be accommodated through the multi-mission procedure described above.
6. Provide for inputting to the model the necessary data to calculate availability and operational readiness.
7. The Poisson models have cost, weight and cube cumulative features. These values are cumulated as parts are added to the provisioning list. Occasions may arise where the minimization of cost, weight and cube would be required. This could be accomplished by the following calculations where the calculation for provisioning purposes is

$$\text{MAX} \left(\frac{\Delta \text{PROB}_i}{\Delta \text{COST}_i} \right)$$

where ΔPROB_i = incremented probability associated with the i-th spared item

ΔCOST_i = cost of i-th item

$\text{MAX} \left(\frac{\Delta \text{PROB}_i}{\Delta \text{COST}_i} \right)$ = maximum provisioning probability for the cost increment

If minimization of weight and cube are desired WEIGHT_i and CUBE_i would be substituted in the denominator.

If the minimization of a combination of the three factors were desired, the following formula could be used

$$\text{MAX} \left(\frac{\Delta \text{PROB}_i}{\text{WT}_1 \cdot \Delta \text{COST}_i + \text{WT}_2 \cdot \Delta \text{WEIGHT}_i + \text{WT}_3 \cdot \Delta \text{CUBE}_i} \right)$$

where WT_1 , WT_2 , and WT_3 are assigned weighting factors for cost, weight and cube respectively and where

ΔCOST_i = proportion of the total allowable cost of the i-th item

ΔWEIGHT_i = proportion of the total allowable weight of the i-th item

ΔCUBE_i = proportion of the total allowable
cube of the i-th item

ΔPROB_i = incremental probability associated
with the i-th item

8. Provide for a simple and effective hand or table lookup solution. Those model (title 20 and 26) that were found and listed under the Poisson model would have to be made comprehensive and effective.

This task deals with the selection of the appropriate type of models to be used for provisioning of electronic equipment(s)/system(s). A review of the literature has lead to the above recommendations to be incorporated in a proposed model. If this task is to be pursued further, the outline of the proposed model above will have to be developed into a detailed procedure and thereafter tested and implemented. Using the computerized model depicted in title 11 which comes closest to approximating the scope of this task and the modifications recommended above, a comprehensive and versatile tool for provisioning electronic equipments/system would be available.

Section VIII
Literature Evaluation
(Form A)

TITLE (MODEL)
FORECASTING
1) A QUEUING APPROACH * QUEUING SYSTEM
TO LOGISTICS SYSTEMS

NOEL M. MIRASOL

2) OPTIMIZATION IN * DYNAMIC MODEL
MULTI-LEVEL SYSTEMS
AND THE THEORY OF
RELIABILITY

WILFRED NIRSCH, H. HEISNER

3) DETECTION OF FAILURE *
RATE INCREASES

G. LORSEN AND T. EISENBURG

4) PREDICTING SPARE *
PART NEEDS

S. S. A. IPIE

COST MINIMIZATION
PROCEDURE FOR
MACHINE PARTS

5) AN APPLICATION OF *
LOGISTIC SUPPORT
NEEDS

H. C. OKRASKI

PHILOSOPHICAL

6) SPARE PARTS FOR *
MACHINES: WHICH ONES
AND HOW MANY

ROBERT C. CHAMBERLAND

OPTIMIZATION
PROCEDURE FOR
COST CONTROL

INVENTORY CONTROL	DISTRIBUTION	MAINTENANCE	AVAILABILITY	STOCKING	DETERMINISTIC	EMPIRICAL	COMMENTS
✓				✓			PERIPHERAL APPLICATION
				✓			PERIPHERAL TO TASK
				✓			PERIPHERAL TO TASK
✓				✓			
						✓	
✓				✓	✓		

* NOT APPLICABLE + APPLICABLE
O RELATED FORM A

TITLE	(MODEL) FORECASTING	INVENTORY CONTROL	DISTRIBUTION	DEPENDENCY	LIMITS	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
7) DETERMINISTIC INVENTORY CONTROL PROCEDURE FOR ELECTRONICS EQUIPMENTS/SYSTEMS R. POWELL AND R. LUTZ	+ BLACK AND RUSCHAN POISSON PROVISIONING MODEL (MODIFIED)					✓			APPLICABLE
8) INITIAL PROVISIONING + WITH SPACE DETERIORATION PAUL J. SCHWEITZER	COMPOUND POISSON PROVISIONING PROCEDURE					✓			CUMBERSON METHODOLOGY BUT APPLICABLE
9) FMSO LOAD LIST + MODEL	BASED ON NORMAL AND POISSON FUNCTION FOR PROVISIONING					✓			
10) FEM LOAD LIST + PREDICTION MODEL (FOR TENDER)	BASED ON NORMAL AND POISSON FUNCTIONS AS WELL AS TABLES FOR COST CONTROL					✓			
11) STOCK PROVISIONING + PROCEDURE FOR THE AN/SPS-40 RADAR ARTHUR RUPP	PROVISIONING BASED ON POISSON FUNCTION FOR EXPONENTIAL PROCESSES STOCKING FOR EQUIPMENT SUB-DEPOTS AND DEPOTS					✓			
12) NEW INVENTORY * ANALYSIS TECHNIQUE JAMES EDGAR						✓	✓	✓	STRESSES A MODIFIED AVAILABILITY MODEL

VIII-3

* NOT APPLICABLE + APPLICABLE
O RELATED

FORM A

TITLE

(MODEL)

FORECASTING

13) TECHNIQUE FOR DETERMINING THE NUMBER OF SPARES WITH A PRESENCE OF UNCERTAINTY LEVEL

N.E. LYNCH AND R.S. MORRIS

14) A METHODOLOGY FOR ESTIMATING EXPECTED USAGE OF REPAIR PARTS WITH APPLICATION TO PARTS WITH NO HISTORY
S.E. HARRER AND R. SITCREAVES

15) THE ALLOWANCE PARTS LIST

16) A MODEL FOR PROCUREMENT, ALLOCATION AND REDISTRIBUTION FOR LOW DEMAND ITEMS
G. HADLEY AND TIM WHITIN

17) OPTIMUM SPARES PROVISIONING

ALLEN D. BRAGG

18) RELIABILITY APPROACH TO THE SPARE PARTS PROBLEM

G.H. EDEL AND A.J. LANE

INVENTORY CONTROL	DEFINITION	AVAILABILITY	PROBABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
				✓			SPARING POLICY FOR DEPOT WARE THAN EQUIPMENT
				✓			ESTIMATING DEMAND FOR ITEMS THAT HAVE A HISTORY OF ZERO DEMAND FOR LONG TIMES
						✓	STANDARDS FOR THE ALLOWANCE PARTS LIST
	✓			✓			STATES THE CONCEPTS INVOLVED IN THE BLACK AND PROSCHAN POISSON MODEL
				✓			

* NOT APPLICABLE
O RELATED

+ APPLICABLE FORM A

(MODEL)
TITLE FORECASTING

INVENTORY CONTROL	DISTRIBUTION	MANAGEMENT	AVAILABILITY	STOCK	DETERMINISTIC	EMPIRICAL	COMMENTS
19) SYSTEM AVAILABILITY * PREDICTIONS H. E. WYNCH						✓	DISCUSSION OF CONCERNS CONCERNING AVAILABILITY
20) ON OPTIMAL REDUNDANCY + POISSON FUNCTION FOR PROVISIONING WITH SERIES CONFIGURATION FOR EQUIPMENT Guy Black and Frank Proschian				✓			
21) OPTIMAL POSITIONING OF INVENTORY STOCK IN A MULTI-ECHELON SYSTEM G. GILBERT, L. SILVERMAN, L. PENRLMAN				✓		✓	INVOLVED WITH PROBLEMS OF REORDERING, HOLDING, COSTS
22) PERFECTABLE (ACQUISITION BASED ON CONSIDERATION OF LOGISTICS EFFECTS) TRIVIAL KATZ	✓					✓	
23) NAVY LOGISTICS * INFORMATION SHARING (NAVLIST)						✓	DISCUSSION OF LOGISTICS ORGANIZATION AND DECISION MAKING
24) ALLOCATION OF SPACES AND * REPAIR RESOURCES TO A LAGRANGE MULTIPLIERS MULTI-COMPONENT SYSTEM FOR COST MINIMIZATION W. S. DEHAY	✓			✓			

VIII-5

* NOT APPLICABLE + APPLICABLE
O RELATED FORM A

TITLE (MODEL) **FORECASTING**

25) RELIABILITY AND MAINTAINABILITY
- MILITARY, THE LOGISTICS CHALLENGE *

GEORGE E. FOUGH

26) SPARE PARTS KITS AT MINIMUM COST + POISSON APPROXIMATING FOR PART TYPES WITH EQUIPMENT REPAIRS BY A SERIES CONNECTION

GUY BUCK AND JOHN PROCTOR

27) STOCK ALLOCATION OF SPARE COMPONENTS *

B. P. LIENIE

28) AN EASY ALLOCATION METHOD ACHIEVING MAXIMUM RELIABILITY + REDUNDANT-STANDBY FIRE EQUIPMENT DESIGN

MASAFUMI SASAKI

29) DYNAMIC PROGRAMMING AND THE RELIABILITY OF MULTICOMPONENT DEVICES * DYNAMIC PROGRAMMING APPROACH APPLICABLE TO EQUIPMENT DESIGN

30) SPARES AND SYSTEM AVAILABILITY + NORMAL PROBABILITY MODEL

J. VANDEN BOSCH

INVENTORY CONTROL	DETERMINATION	MAINTAINABILITY	AVAILABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
				✓		✓	
				✓			
✓				✓			RELATED BUT NOT APPLICABLE
				✓			
				✓			
			✓	✓			

* NOT APPLICABLE + APPLICABLE FORM A
O RELATED

(MODEL) FORECASTING

TITLE	INVENTORY CONTROL	DISTRIBUTION	MAINTAINABILITY	AVAILABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
31) A MONTE CARLO APPROACH + TO SPACE PROVISIONING R. S. SEBENY				✓	✓			
32) AN OPTIMAL ALLOWANCE + LIST MODEL MINA H. GOURARY					✓			
33) RESOURCE ALLOCATION IN A STOCHASTIC FLOW PROCESS WITH AN APPLICATION TO THE NAVAL REPAIR SYSTEM L. D. SILVERMAN	✓	✓			✓	✓		
34) OPTIMAL SPARES FOR STOCHASTICALLY FAILING EQUIPMENTS S. S. SUTTON, R. LLOYD	✓	✓			✓	✓		
35) AN APPLICATION OF NETWORK ANALYSIS TO THE DETERMINATION OF MINIMAL COST AIRCRAFT PIPELINE FACTORS C. H. FALNER	✓					✓		
36) POLARIS LOGISTICS STUDY + PROVISIONING BASED ON THE NEGATIVE BINOMIAL DISTRIBUTION M. DENICOFF, J. FENNELL S. HAGER, W. HARLOW F. SERGEL, H. SOLOMON							✓	

* NOT APPLICABLE + APPLICABLE
O RELATED

FORM A

TITLE	(MODEL) FORECASTING	INVENTORY CONTROL	DISTRIBUTION	MANUFACTURING	AVAILABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
32) POLARIS LOGISTICS STUDY + #2 POLARIS ALLOWANCE INPUT DATA DENICOFF, FENNEL, HARLOW, SOLOMON	PROVISIONING PROCEDURE BASED ON THE NEGATIVE BINOMIAL FUNCTION								STANDARDS AND RECOMMENDATIONS FOR INPUT DATA
38) POLARIS LOGISTICS STUDY + #3 A POLARIS LOGISTICS MODEL DENICOFF, FENNEL, HARNER, SOLOMON	PROVISIONING PROCEDURE BASED ON THE NEGATIVE BINOMIAL FUNCTION					✓			
39) OPNAV 4423.4 * PROVISIONING OF END ITEMS OF MATERIALS PROVIDING END ITEM BY CONTAINERS	PROCEDURES FOR PROVIDING END ITEM BY CONTAINERS							✓	
40) OPNAV INSTRUCTIONS + 4441.12A SUPPLY SUPPORT OF THE OPERATING FORCES						✓	✓		
41) STATISTICAL CALCULATIONS * FOR THE LOGISTICS OF ENGINE REPAIRS (SCALER) METHOD JAMES P. MATTHESEN, PH.D.						✓			
42) THE THEORY OF RELIABILITY * FOR DESIGN FOR LOGISTICS FORECASTING JAMES H. BRADY	PHILOSOPHICAL							✓	

* NOT APPLICABLE + APPLICABLE FORM A
X RELATED

TITLE (NAME) FORECASTING

TITLE	INVENTORY CONTROL	DISTRIBUTION	MAINTENANCE	REPAIRABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
35) IMPACT OF ADVANCED LOGISTICS CONCEPT ON AN /SRG-20 FAMILY EQUIPMENTS * G. A. COHEN (1974)					✓			PROPOSAL FOR RELIABILITY MODEL AND DEPT PROVISIONING
36) THE DESIGN OF MILITARY SUPPLY TABLES FOR SPARE PARTS (1958) O M. A. GRISER AND R. W. KARR					✓			METODOLOGY USABLE OR TO BE CONSIDERED FOR TABLE LOOKUP FOR SPANNING
37) THE (S-I, S) INVENTORY POLICY UNDER COMPOUND POISSON DEMAND A THEORY OF RECOVERABLE ITEM STOCKAGE * J. G. FEEHENY AND C. C. SHEPARDSON					✓			INVENTORY MANAGEMENT FOR REMAINABLE ITEMS
38) THE INITIAL PROVISIONING DECISION FOR INSURANCE TYPE ITEMS * R. W. BURTEN AND S. C. JARQUETTE					✓	✓		PRELIMINARY APPLICATION TO TASK
39) PLANNING BY RESOURCE ALLOCATION METHODS * J. L. TAYLOR AND J. E. WALSH	✓				✓	✓		
40) AN EVALUATION OF A TECHNIQUE TO DETERMINE ITS APPLICABILITY + RONALD D. OGLESBY				✓	✓			

* NOT APPLICABLE + APPLICABLE FORM A
O RELATED

TITLE

FORECASTING

TITLE	INVENTORY CONTROL	DISTRIBUTION	HANDLING	AVAILABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
1) LOGIC CHART COMPUTATION + OF FLICP COSALS FLEET MATERIAL SUPPORT OFFICE MECHANICSBURG, PA							✓	
2) INVENTORY CONTROL WITH * PROBABILISTIC DEMAND AND PERIODIC WITHDRAWALS W. H. HAUSHMAN AND L. J. THOMAS	✓				✓			NOT IN AREA OF TASK
3) MAINTENANCE ROUTES WHEN * FAILURE DISTRIBUTION OF EQUIPMENT IS ONLY APPROXIMATE D. G. FETTER			✓		✓			OUTSIDE REQUIREMENTS OF TASK
4) CALCULATING THE RELIABILITY * OF RESTORABLE SYSTEMS WHILE TAKING INTO ACCOUNT THE WORKING SHIFTS OF MAINTENANCE PERSONNEL D. G. FETTER			✓		✓			NOT APPLICABLE TO TASK
5) RELIABILITY - CENTERED * MAINTENANCE MAJOR GENERAL E. H. JOHANSEN							✓	NOT APPLICABLE TO TASK
6) AN INVENTORY MODEL FOR * REPAIR PARTS - APPROXIMATIONS IN THE CASE OF VARIABLE DELIVERY TIME M. J. BECKMANN	✓				✓			NOT APPLICABLE TO TASK

* NOT APPLICABLE
O RELATED

+ APPLICABLE FORM A

(MODEL) FORECASTING

TITLE	INVENTORY CONTROL	DISTRIBUTION	MAINTAINABILITY	AVAILABILITY	STOCHASTIC	DETERMINISTIC	EMPIRICAL	COMMENTS
69) A UNIFIED MODEL FOR DEMAND PREDICTION IN THE CONTEXT OF PROVISIONING AND PROCUREMENT S. E. HANCOCK AND R. SITGREAVES	✓				✓			IMPROVEMENT OF DEMAND PREDICTION NOT APPLICABLE TO THIS
68) A REPLACEMENT POLICY FOR COMPONENTS OF A PURE SERIES SYSTEM UTILIZING ONE COMPONENT AS AN INDICATOR OF REPLACEMENT THE COMPONENTS. M. G. OPPEN					✓			REPLACEMENT PROCEDURE FOR SUB SYSTEMS COMPONENTS NOT APPLICABLE
69) ON CHOOSING A FAMILY OF PROBABILITY DISTRIBUTIONS FOR LEAD TIME DEMAND F. R. RICHMONDS AND M. M. RUSSELL					✓			INTUITIVE AND THEORETICAL ARGUMENTS PRESENTED NOT FEASIBLE
70) INITIAL PROVISIONING OF A STANDBY SYSTEM WITH PREDETERMINING AND REPAIRABLE D. J. JASNETTE					✓			NOT APPLICABLE
71) A REVIEW OF MILITARY ESSENTIALITY CODING AND SHIPBOARD ALLOWANCE COMBINATIONS J. A. MONTALAGAVE							✓	PERIPHERAL ARTICLE CONCERNING THIS PERIPHERAL
72) BEST REPLACEMENT FACTOR F. C. STRAUCH							✓	PERIPHERAL ARTICLE CONCERNING THIS PERIPHERAL

TITLE (MODEL) FORECASTING

TITLE	DEMAND FORECASTING WITH PROGRAM. FACTORS	INVENTORY CONTROL	DISPATCH	MANAGEMENT	AVAILABILITY	STOCKS	DETERMINISTIC	EMPIRICAL	COMMENTS
DEMAND FORECASTING WITH PROGRAM. FACTORS	* MATHEMATICAL PROCEDURE						✓	✓	DIFFERENT APPROACH TO DEMAND FORECASTING
DEMAND FORECASTING WITH PROGRAM. FACTORS	* POLYNOMIAL (EXPONENTIAL) SMOOTHING MODEL					✓			NOT APPLICABLE
DEMAND FORECASTING WITH PROGRAM. FACTORS	* TECHNIQUES FOR HELICOPTER (SUB-SYSTEMS)								USING HISTORICAL DEMAND TO PROJECT FUTURE DEMAND
DEMAND FORECASTING WITH PROGRAM. FACTORS	ROBERT E. MARKLAND								PROFORE NOT ADEQUATE FOR LOW DEMAND ITEMS

NUMEROUS OTHER ARTICLES WERE REVIEWED HOWEVER, THE TITLES SUGGESTED THAT THE CONTENTS WERE NOT APPLICABLE OR PERIPHERALLY APPLICABLE TO THE TASK ASSIGNMENT

* NOT APPLICABLE
O RELATED

+ APPLICABLE

FORM A

Literature Evaluation

Form B

Only title numbers applicable to the task
Assignment are listed on this form.

Title No. 7

Subject: Optimum Spare Provisioning for Electronics Equipment/
Systems

Literature Source: Naval Engineering Journal, Feb. 1970 R. I. Powell and
R. D. Lutz

Purpose: Alternative to the part probability method used by
Fleet Logistics Supply Improvement Program (FLESHIP).

Model: Spare provisioning model of Black and Proschan (Poisson
process)

Input: Failure rates, costs

Output: Equipment/System effectiveness vs. costs

Comments: Method is based upon the Poisson function assuming a
series configuration to derive a probabilistic effect-
iveness for equipment(s)/systems.

Subject: Initial Provisioning with Spare Deterioration

Literature Source: Operations Research, Vol. 15, May 1967, Initial Provisioning with Spare Deterioration, Paul J. Schweitzer

Purpose: A study to determine the steps required to establish a spare parts provisioning procedure under the assumption that spare parts lifetimes deteriorate.

Background: Spare provisioning procedures usually assume that (1) spare parts do not fail on shelf, (2) spare parts have the same failure rates as parts in use. A study has indicated that even a small amount of spare deterioration results in serious degradation of system reliability.

Model: System of N identical parts with an initial supply of M parts. The N parts are assumed to fail independently each with a constant failure rate λ while the spare parts are assumed to fail independently with a constant failure rate λ_s . Compound Poisson function used to derive spare part depth.

Input: Failure rates, failure rates for spare equipments (weighted), probability provisioning goal for equipments, operating time

Output: Equipment spares for operating time (t).

Comments: A graphic method for determining spare requirements necessary for a mission of specified operating time with a preset probability provisioning level. Hand calculations are cumbersome requiring interpolation. Applicable to reliable equipments requiring a small number of spare parts in that the calculations are cumbersome.

Title No. 9

Subject: FMSO Load List Model

Literature Source: Load List Manual, Navy Fleet Material Support Office, Mechanicsburg, PA

Purpose: Provide load list quantities for the three levels of material support: Individual ship, mobile logistic support force and selected shore activities, and depots that serve to supply the other two levels

Background: A method simple enough to understand and apply was required.

Model: Load list is based upon rates derived from historical demand data, population and failure data and technical overrides. With the mean demand and variation in demand for specified time periods, load lists are calculated based upon the normal and poisson distributions. The criticality of a part is assigned a risk factor which is used for generating the load lists.

Input: Average demand (3 month), variation in demand, number of applications, risk control parameters

Output: Load lists for individual ships, mobile logistic support force and selected shore activities and depots

Comments: No overall protection level is obtainable under this procedure. Relation between cost and mission effectiveness is not obtainable. Sparing is on a per item or unit basis, dependent upon demand, demand variation and risk control (weighting) parameters.

Subject: FBM load list prediction model.

Literature Source: ALRAND working memorandum 304-FBM load list prediction model, 20 May 1977

Purpose: Provide Tender load list quantities for use during the provisioning of SSBN hull for mechanical, electrical, electronic or ordnance equipments

Background: The TLL (Tender Load List) computation models for determining range and depth derives quantities which vary with original provisioning quantities and excesses/shortages result. Provisioning technicians need an equation or table to determine range and depth of items that will be easy to use and practical.

Model: The procedure is based on the QAD (quarterly average demand) where items have a demand history of two or more years. Where history is lacking the QAD is the product of the BRP (best replacement factor) and the population to be supported. The Poisson distribution is assumed to be descriptive where the forecasted QAD is one or less and the normal distribution is assumed where the QAD is greater than one.

Input: QAD's, BRP's, number of part applications per part, price, risk control parameter.

Output: Tender load lists with and without constraints on price and stocking levels per part type.

Comments: This procedure is a supplement to the tender load list computational model. This procedure has the option of imposing arbitrary constraints such as a maximum of \$100.00 per unit/fifty unit types. The load list levels are dependent on the assigned risk control parameter which is an input of the model.

Subject: Stock list provisioning procedure with detailed AN/SPS-40 radar application

Literature Source: Technical report number 01862.01-1 stock list provisioning procedure with detailed AN/SPS-40 radar application
Arthur Rupp

Purpose: A logistic study to determine the procedure required to establish a spare parts provisioning list and to develop a computer program for performing the necessary calculations.

Background: During the performance of equipment evaluation by the electronics maintenance engineering center, it was found that a major source of difficulties resulted from inadequate logistic support. The logistic problem was found to be acute on the AN/SPS-40 radar system.

Model: The provisioning procedure is based on the Poisson probability function. It is assumed that equipment parts have a series configuration and that parts are added to the equipment in a standby status until a provisioning probability goal has been met. Provisioning probability goals can be set for equipments, sub-depots and depots (e.g. Provisioning levels could be set as follows: .90 for a 3 month stock period for equipments, .93 for 6 months for 6 equipments for sub-depots and .99 for one-year for 42 equipments for the depot).

Input: Part type, part name, cube, weight, price, number of applications, replacement rates, assigned provisioning probability goals (for equipment, sub-depot, depot) for specified calendar times.

Output: Stock lists for equipment, sub-depot, and depot with the associated price, cube and weight.

Comments: With minor modifications the computer program can be adjusted to generate provisional probability goals with a cost minimization feature. With repair time data, the operational readiness of the equipment can be determined thru the computer run.

Title No. 13

Subject: Technique for Determining the Number of Spares with
a Prechosen Probability Level

Literature Source: Tenth Annual Reliability and Mathematical Conference,
Annals of the Assurance Sciences, Anaheim, California,
1971, N. E. Lynch and R. S. Norris

Model: The basis of the technique is that the density function
of a sum of independent random variables approaches
the normal density function regardless of the type
of density function each of the variables had.

This assumes a sparing of unlike equipment for different
operating time at sites such as a depot. Provisioning
goal is set. No cost optimization procedure.

Comments: The method is cumbersome. It needs someone with a
statistical background to interpret the results.

Subject: A Methodology for estimating expected usage of repair parts with application to parts with no usage history

Literature Source: Naval Research Logistics Quarterly, Vol. 17, Dec. 1970, S. E. Haber and R. Sitgreaves

Purpose: Develop a sparing procedure for part types that have no usage estimates

Background: Handling usage estimates with zero values over long periods of time

Model: Repair part demands are assumed to be Poisson distributed while their means are assumed to be Gamma distributed. Alike type of items are pooled for estimating usage rate for zero demand items.

Comments: The method is peripheral to the task assignment.

Title No. 15

Subject: The allowance parts list

Literature Source: Newsletter, December 1975, R. G. Hakemian

Purpose: Defining the procedures and philosophy involved in generating the allowance parts list

Background: Procedure used by Navy for generating shipboard parts list.

Model: Procedural model

Comments: Any sparing model for the Navy would have to consider the procedures and concepts as described in this write up. Procedures are required for the task assignment.

Subject: Reliability Approach to the Spare Parts Problem

Literature Source: George H. Ebel and Andrew Lang

Purpose: Develop a procedure whereby unskilled personnel, using charts and tables can select the number of spare parts required to support a given program.

Model: Poisson function for provisioning of parts

Input: Failure rates, applications per part type

Output: Spart part number per part type

Comments: A procedure using graphs has been developed for calculating spare part needs. Confidence limits have been calculated to determine whether certain part types may fall critically short.

Subject: On optimal redundancy

Literature Source: Operations Research, Vol. 7, 1959, Guy Black and Frank Proschan

Purpose: Provide spare part kit for new equipment

Model: A complex system is to be placed in the field for a fixed period. During the period only the spares initially provided may be used to replace components that have failed. Independence of failures is assumed among the essential components considered. Given the cost of components, the number of like components of each type simultaneously operating, the length of operation scheduled for each component, the failure distributions of components, a general mathematical solution is obtained for the composition of the spare parts kit which maximizes assurance of continued operation during the period, subject to a fixed budget for spares. Explicit formulas are obtained in the case of exponential failure distributions, constructive procedures in the case of monotone likelihood ratio densities. Fortunately, the identical mathematical model is applicable in determining the optimal allocation of redundancy in designing system reliability under a weight or cost restraint.

Comments: Poisson provisioning with equipment represented by series configuration. Cost minimization also derived.

Subject: Spare part kits at minimum cost

Literature Source: Proceeding - Fifth National Symposium on Reliability and Quality Control, 1959, Guy Black and Frank Proschan

Purpose: Provide spare part kit for new equipments

Model: Poisson function with equipment represented by series configuration

$$P(x) = \prod_{i=1}^r \left(\sum_{x=0}^n \frac{(\lambda t)^x e^{-\lambda_i t_i}}{x!} \right)$$

where: P = provisioning probability goal
r = part type size
n = depth of part type
x = part type
 λ = failure rate of part type
t = time (operating)

Input: failure rates, part type, price and no. of operating hours, part type size, provisioning goals

Output: spare kit for specified operating time with a cost evaluation procedure

Subject: Spares and Systems Availability

Literature Source: Proceedings, 1976 Annual Reliability and Maintainability Symposium, Wm. J. Vonden Bosch

Purpose: To predict the expected system availability, number of hours between restocking spares, number of spares necessary, expected time system will be down and minimize cost.

Model: Technique for determining the number of spares necessary for a system or groups of systems utilizing a pre-chosen probability level that sufficient spares would be available. The basis for this technique was that the density function of a sum of independent random variables approaches the normal density function, regardless of the type of density function each of the variables had.

Comments: The claim made is the methodology and application is simple. This is not true but the approach is interesting.

Subject: A Monte Carlo Approach to Spare Provisioning

Literature Source: R. J. Sebeny

Purpose: Simulated technique for stocking equipment(s)

Background: The program described in the paper illustrates a method of provisioning spares for a complex system on the basis of their impact on system availability and cost. Through the use of a Monte Carlo technique, a wide variety of system configurations and maintenance practices can be simulated and analyzed. Also, by employing a computer generated table describing system success as a function of assembly status, the input data required to use the program is greatly simplified. Input data is "user" oriented requiring only knowledge of system operation and maintenance practices thus permitting use of the program by personnel of varied disciplines.

Model: Simulation, monte carlo technique, probabilistic using Poisson function and fault tree type of model for the system.

Input: Failure Rates, repair rates

Output: System reliability and availability

Comments: It is necessary to develop a computer model for each equipment. The methodology in that sense is not general enough in that these computer models of the system may be extensive. The limits of a computerized model are restricted. This restricts the size of an equipment to be handled.

Subject: An optimal allowance list model

Literature Source: Mina Haskino

Purpose: The problem we shall consider can be stated as follows: How does one properly stock a vessel with necessary commodities, subject to the limitations of available space? This entails a decision on the number of commodities to be carried, the quantity of each commodity to be stocked, and the relative weight (i.e., "military worth", etc) to given each commodity, all subject to the overriding considerations of space. In this paper we shall attempt to treat a somewhat idealized version of this problem by a method which might be extended to more complicated situations.

Model: Expected demand, normal distribution, lagrange multipliers for optimization, with weighting factors to consider the factor of essentiality

Input: Expected demand for mission, total allowable cost, weight or cube

Output: Part lists with constraints of cost, weight or cube

Title Nos. 36-38

Subject: POLARIS Logistics Studies 1, 2, 3
Study 1 -- Military Essentiality System (AD 603 385)
Study 2 -- Allowance List Input (AD 294 633)
Study 3 -- Logistics Model (AD 416 391)

Literature Source: Defense Documentation Center, Defense Logistics Agency,
Cameron Station, Alexandria, Virginia; by Marvin Denicoff,
Joseph Fennell, W. H. Manlow and Henry Solomon

Model: Sparing based upon demand rate (2-3 month basis). Using
the negative binomial demand model and coefficient of
variation. Sparing is on a part basis by means of table
lookup. Scaling factor and essentiality factors have
been developed and proposed for use.

Input: Demand rate, variance, price, weight, cube, holding
cost, shortage cost, scaling parameters, essentiality
factors

Output: Spare parts for part types, cost, weight, cube for hull

Comments: Sparing is on a part basis

Subject: OPNAV Instruction 4441.12A, Change Transmittal #2

Literature Source: Department of the Navy, Office of the Chief of Naval Operations

Purpose: Supply support of the operating forces. To prescribe range and depth of material to be carried by individual ships.

Model: Heuristic model. Range and depth of provisioning based on definitions of (1) demand based items, (2) military essentiality, (3) low demand items and (4) net effectiveness concept.

Subject: An Evaluation of a Technique to Determine its Applicability (1973)

Literature Source: National Technical Information Service, U. S. Department of Commerce, Springfield, VA, Ronald D. Oglesby

Purpose: Calculate number of spares needed to meet a predetermined probability projection level with a minimum of system down time

Background: Evaluation of a technique based on the central limit theorem

Model: Normal model based on the central limit theorem

Input: Number of systems (or parts), time (operating), mean of different processes, associated variance third moment, and the desired probability level

Output: Probability level, number of spares per system(s)

Subject: Logic Chart Computation of FILSIP COSALS

Literature Source: Navy Fleet Material Support Office, Mechanicsburg, PA

Purpose: Describe procedure used for component provisioning of COSALS.

Model: A model based on demand or expected demand and the Poisson function for determining depth of items.

Input: Best replacement factor, demand(s), various restrictive criteria on demands

Output: Range and depth of provisioned items.

Literature Evaluation
Form C

OUTPUTS

INPUTS

MODE OF
CALCULATION

DATES PROVISION FOR

TOTAL

COMMENTS

PRICE
WEIGHT
CUBE/SPACE
TARE/SPACE
TARE TYPE
SPACE PER
TARE TYPE

PRICE
CUBE
WEIGHT
TARE/SPACE
REPLACEMENT
DEMAND
FUTURE
REPAIR
EQUIPMENT
EQUIPMENTS
SUB-DEPT
DEPT

HAND
TABLES
COMPUTER

TITLE
PROVISIONING
MODEL

1) OPTIMUM SERIES
BASED ON
PROVISIONING METHOD
FOR ELECTRICITY
EQUIPMENTS (POISSON
METHOD)

2) INTERNAL PROVISIONING COMPOUND
WITH SPACE
POISSON
FUNCTION

9) FRIED LOAD
LIST MODEL
PART PROVISIONING
BASED UPON
NORMAL AND
POISSON
FUNCTIONS

10) FRIED LOAD
LIST MODEL
(TENDER)
BASED ON
FRIED
MODEL

11) STOCK PROVISIONING COMPOUND
BASED ON
FRIED LOAD
FOR EQUIP.
PROVISIONING
ANALYSIS TO DETERMINE
PROCEDURE

12) TECHNIQUE FOR
DETERMINING THE
NUMBER OF SERIES
WITH A PRECHISEN
ACCURACY
NORMAL
MODEL

FORM C

TITLE	PROVISIONING MODEL	MODE OF CALCULATION		INPUTS										OUTPUTS									
		HAND TABLES	CORRECTOR	POST DATA	PRICE	CODE	WEIGHT	HEIGHT	REACH	LEAD	FAILURE	TYPE	EQUIPT	EQUIPTS	SUB-DEPT	DEPT	POST TYPE	WEIGHT/SPACE	POST/SPACE	PRICE	WEIGHT	CODE	COMMENTS
31) A WHITE CARLO APPROACH TO SPARE PROVISIONING	COMPUTER MODEL OF EQUIPMENT, SIMULATION OF FAILURES WITH RANDOM NUMBER GENERATOR		✓	✓	✓		✓	✓		✓			✓				✓	✓	✓	✓			
32) THE NORMAL ALLOCATOR LIST	NORMAL MODEL	✓		✓	✓	✓	✓	✓		✓							✓	✓	✓	✓			
36-37) MILITARY LOGISTICS STUDY #1, 2, 3	NEGATIVE BINOMIAL MODEL WITH ESSENTIAL CASES AND WEIGHTING FACTORS	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
40) OPNAV INSURANCE ANALYSIS	NORMAL AND POISSON DISTRIBUTION FUNCTIONS	✓		✓		✓		✓				✓	✓	✓	✓	✓				✓	✓	✓	
61) COMPUTATION OF F. S. TOTAL	POISSON DISTRIBUTION FUNCTION DEPTH	✓		✓		✓		✓				✓	✓	✓	✓	✓							
62) EVALUATION OF A TECHNIQUE TO DETERMINE ITS RELIABILITY	NORMAL MODEL		✓			✓		✓		✓			✓	✓	✓	✓							

FORM C.

Section IX

Glossary

- Allowance Parts List (APL) -The technical portion of the COSAL. Identified by individual equipment. The parts which are candidates for ship's allowance, including initial range and depth as well as maintenance and supply instructions for each part.
- Availability -The probability than an equipment/system is operating satisfactorily in time when used under stated conditions where the total time considered includes operating time, active repair time, administrative time and logistics time.
- Best Replacement Factor (BRF) -A usage rate which represents the best estimate of annual usage of an item for each installation of that item. If the BRF is 1 or greater for a 90 day period it is considered a demand item if it is less than 1 but greater than .25 for a 90 day period it is considered as an insurance item provided it is critical for a ship's mission.
- Coordinated Shipboard Allowance List (COSAL) -Document which lists the equipment, components, repair parts, consumables, and operating space items required for an individual ship to perform its operational mission.
- Critical Item -An item considered vital for the success of a mission/or function of an equipment/system.
- $\bar{D}_{RP}$ -Average demand rate per part.
- Demand Base Items -Those items used aboard ships at least once during a 90 day period, has a .90 probability of filling total demand for these items over the entire operating period.
- Depth -The quantity of items on a load list.

FLSIP	-Fleet Logistic Support Improvement Program. A procedure which incorporates the requirements of OPNAV 4441.12A and the APL for stocking a hull (see procedures in title 61).
Follow-on Provisioning	-Subsequent provisioning for an equipment/system.
Gross Effectiveness	-How well the load meets the demand for all items whether they are involved in the range of the load list or not. The gross effectiveness goal is set at 65%. Gross effectiveness is calculated as the demand satisfied by the demand received of requisitions for load list items plus other items.
Initial Provisioning	-The first-time provisioning for an equipment/system.
Insurance Items	-Those items which a demand of .25 or greater usage in 1 year but less than a demand base item. It will be selected only if essential to the support of equipment considered vital to the ship's mission.
Long Life	-Those items having a demand .25 or less usage in 1 year. These items are not stocked aboard ship.
Military Essentiality Code (MEC)	-Currently there are two classifications under this class of items -- critical and non-critical with most items being classed as critical (over 90%)
Mission (Reliability)	-The probability of non-failure of the equipment/system for the period of time to complete a mission.
Multi-mission	-Subsequent time periods (missions) within which an equipment/system would be operable.
Net Effectiveness	-How well the load meets the demand for items on the load itself. The net effectiveness goal is set at approximately 85%. Net effectiveness is calculated as the demand satisfied by the demand received of requisitions for load list items.

Normal Usage	-Peacetime operating stock level.
Operational Readiness	-The probability that an equipment/system is either operating satisfactorily or is ready to be placed in operation on demand under stated conditions. It would be represented by reliability times availability.
Provisioning	-A process for determining the range and depth of support items necessary to operate and maintain an end item of material for a specified period of time.
Provisioning Effectiveness	-The probability that sufficient spare items are available at a site in order to meet a prescribed probabilistic goal based on a stochastic model.
Provisioning Level	-A probabilistic value assigned for provisioning an equipment(s)/system(s).
Range	-The variety of items on a load list.
Reliability	-The probability that an equipment/system will perform satisfactorily for a given time when used under stated conditions.
Spares	-Items that are to be used as repairable items.
Technical Overrides	-Those items used to support newly deployed equipment and to support critical equipments.

Section X

Bibliography

The following abstracts were reviewed for source material which served as major source documents for literature evaluations.

Science and Technical Aerospace Reports -- 1974-79
Institute of Electronics and Electrical Engineers (IEEE) --
1974-79

Logistics Spectrum -- 1974-79

Management Science -- 1974-79

Operations Research -- 1974-79

Proceedings of Reliability and Maintainability -- 1974-79

Applied Science and Technology Index -- 1974-79

Naval Research Logistics Quarterly Index -- 1974-79

Mathematical Reviews -- 1974-79

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Provisioning -- 1979

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Appendix A

Applicable Literature Source List

Listed are the literature sources (called titles in section VI) that were selected as being applicable and related to the task. They appear under a separate cover but the title numbers and literature sources are as follows:

<u>Title No.</u>	<u>Literature Source</u>	<u>Author</u>
7	Provisioning for Electronics Equipments/Systems	R. Powell and R. Lutz
8	Initial Provisioning with Spare Deterioration	Paul J. Schweitzer
9	FMSO Load List Model	
10	FBM Load List Prediction Model (for Tender)	
11	Stock Provisioning Procedure for the AN/SPS-40 Radar	Arthur Rupp
13	Technique for Determining the Number of Spares with a Prechosen Probability Level	N. E. Lynch and R. S. Morris
14	A Methodology for Estimating Expected Usage of Repair Parts with Application to Parts with no History	S. E. Haber and R. Sitgreaves
15	The Allowance Parts List	
18	Reliability Approach to the Spare Parts Problem	C. H. Ebel and A. J. Lang
20	On Optimal Redundancy	Guy Black and Frank Proschan
26	Spare Parts Kit at Minimum Cost	Guy Black and Frank Proschan
30	Spares and System Availability	J. Vanden Bosch

<u>Title No.</u>	<u>Literature Source</u>	<u>Author</u>
31	A Monte Carlo Approach to Spare Provisioning	R. S. Sebeny
32	An Optimal Allowance List Model	Mina Gooray
36-37-38	POLARIS Logistics, Studies 1, 2, 3	M. Denicoff, J. Fennell, S. Haber, W. Marlow, F. Segel, H. Solomen
40	OPNAV Instruction 4441.12A, Supply Support of the Operating Forces	
60	An Evaluation of a Technique to Determine its Applicability	R. D. Oglesby
61	Logic Chart Computation of FLSIP COSALS	

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