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CONVENTIONAL AS LOAD LIST STUDY, (U)  
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CONVENTIONAL AS LOAD LIST STUDY

REPORT 130

PROJECT 971260

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## ABSTRACT

This study evaluates alternative techniques for computing conventional submarine tender load lists, given specified performance goals. Areas that are evaluated include: (1) the use of alternative demand distributions; (2) the use of alternative techniques for controlling range; and (3) the use of alternative optimization models. Alternatives are evaluated separately for equipment-related and nonequipment-related items. The various techniques are evaluated using actual submarine demand data. The models are evaluated in terms of units effectiveness, requisitions effectiveness, and range effectiveness. A common model is recommended for computing conventional and FBM (Fleet Ballistic Missile) submarine tender load lists.

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## EXECUTIVE SUMMARY

1. Objective. The objective of this study is to evaluate the current conventional submarine tender load list model, determine if there is a more cost-effective model, and determine whether the same model can be used to support both the conventional and FBM submarines.
2. Approach. The current conventional submarine tender load list model uses the Normal distribution to describe item demand. The effectiveness goal for the load list is based on units short. A range cut based on predicted AQD (Average Quarterly Demand) is used to achieve the desired range, and depth is computed using a variable protection model designed to satisfy essentiality-weighted units short. For items with a demand history, demand is used as a measure of essentiality. For items with no historical demand, essentiality is based on the vital/nonvital MEC (Military Essentiality Code). This study evaluates possible changes to computational techniques in the current model, given a specified performance goal. Areas that are examined and evaluated include: (1) the use of alternative demand distributions; (2) the use of alternative techniques for controlling range; and (3) the use of models that minimize units short, requisitions short, demand-weighted units short,

demand-weighted requisitions short, and essentiality-weighted units short.

All test load lists in this study are based on the AS 36 candidate file provided by SPCC (Navy Ships Parts Control Center) and two years of demand history from the supported submarines. The test loads are built to support a specified effectiveness goal. The model parameters are varied from run to run until the predicted effectiveness goals are met. The test load lists are then evaluated by comparing 90 days of actual demand data to the load list quantities. The models are evaluated in terms of units effectiveness, requisitions effectiveness, and range effectiveness. Equipment-related and nonequipment-related items are evaluated separately.

3. Findings. For equipment-related items, a combined Normal-Poisson distribution described demand most accurately of the alternatives tested. An optimization model minimizing demand-weighted units short outperformed the other models tested.

For nonequipment-related items, the Normal distribution and a combined Normal-Poisson produced very similar results (both better than the Poisson). The Normal distribution performed slightly better (less than 1% difference in effectiveness) than the combined distribution, but also cost slightly more. An optimization model that minimizes demand-

weighted requisitions short outperformed the other models tested. Findings for the conventional submarine tender study were compared with the FBM load list study (reference 1) and found to be consistent.

4. Recommendations. It is recommended that a single model be approved for both FBM and conventional submarine tender load lists. Specifically, it is recommended that the equipment-related item computations be based on an optimization model that minimizes demand-weighted units short and that a combined Normal-Poisson distribution (based on the size of the AQD) be used to describe item demand. For nonequipment-related items, it is recommended that computations be based on an optimization model that minimizes demand-weighted requisitions short and that the combined Normal-Poisson distribution (based on the size of the AQD) be used to describe item demand.

## I. INTRODUCTION

Reference 1 evaluated alternative models for the FBM submarine tender load list and recommended certain changes to produce a more cost-effective load. The purpose of this study is to determine whether similar changes would improve conventional submarine tender load list performance.

The current conventional submarine tender load list model uses the Normal distribution to describe item demand. The goal for the load list is a net units effectiveness of 90%. A range cut based on predicted AQD is used to achieve the desired range, and depth is computed using a variable protection model based on essentiality-weighted units short. For items with a demand history, demand is used as a measure of essentiality. For items with no historical demand, essentiality is based on the vital/nonvital MEC.

This study evaluates possible changes to the computational techniques described above. Areas that are examined and evaluated include: (1) the use of the Poisson distribution in lieu of the Normal distribution to describe item demand; (2) the use of alternative techniques for controlling range; and (3) the use of models that minimize demand-weighted units short, units short, demand-weighted requisitions short, or requisitions short.

## II. APPROACH

All test load lists in this study are based on the AS 36 candidate file provided by SPCC and two years of demand history from the supported submarines. The test loads are built to support a specified effectiveness goal. Specifically, the model parameters are varied from run to run until the predicted effectiveness goals are met. The test load lists are then evaluated by comparing 90 days of actual demand data to the load list quantities. The candidate file and the evaluation file used in this study are discussed in more detail below.

A. LOAD LIST CANDIDATE FILE. The load list candidate file employed in the most recent AS 36 production cycle was used to create the alternative test load lists. The ER (Equipment-Related) and NER (Nonequipment-Related) items are tested separately. An item is said to be an ER item when it is on the ICP (Inventory Control Point) candidate file of Allowance Parts List items. An item is said to be a NER item when it has historical demand, but it is not on the ICP candidate file.

There were 92,719 ER load list candidate items, of which 10,044 (about 11%) had historical demand. Characteristics of the key data elements are shown in APPENDIX B and summarized

below:

. 47% of the ER load list candidate items had a predicted AQD of .05 or less, i.e., less than one demand in five years.

. Only 11% of the ER load list candidate items had a predicted AQD greater than 1.00, i.e., greater than four units a year.

. 94% of the ER load list candidates had an average requisition size of zero or one.

. 51% of the ER load list candidates had a unit price of \$5 or less and 85% had a unit price of \$100 or less.

There were 9,636 NER load list candidate items. Of these, 6,198 items were excluded because they had only a single demand frequency or a total two year demand quantity of less than four units. Characteristics of the remaining 3,438 NER items are shown in APPENDIX C and summarized below:

. 54% of the NER load list candidate items had a predicted AQD of three or less, i.e., 12 or less units per year.

. 12% of the NER load list candidate items had a predicted AQD greater than 20 per quarter, i.e., over 80 units

per year.

. 2% of the NER load list candidates had an average requisition size of one.

. 24% of the NER load list candidates had an average requisition size greater than ten.

. 68% of the NER load list candidates had a unit price of \$5 or less and 97% had a unit price of \$100 or less.

B. EVALUATION DEMAND DATA. The AS 36 test loads were based on demand history from the supported submarines for the period November 1974 through October 1976. The loads were evaluated using demands from the same submarines for the period November 1976 through January 1977. These data are assumed to be representative of a typical quarter.

The alternative load lists were evaluated in terms of range effectiveness, requisitions effectiveness, and units effectiveness. For this study, effectiveness was based only on FMSO (Navy Fleet Material Support Office) load list candidate items, i.e., demands for items not on the candidate file were excluded from effectiveness computations. Range effectiveness refers to the number of AS 36 tender load list candidate NIINs (National Item Identification Numbers) demanded and satisfied divided by the number of AS 36

candidate NIINs that were demanded. A NIIN is counted as satisfied when the item demanded is on the load list. Requisitions effectiveness refers to the number of requisitions demanded and satisfied divided by the number of requisitions demanded. A requisition is said to be satisfied when there are enough units of the item available to at least partially fill the requisition. Units effectiveness refers to the number of units demanded and satisfied by the load list quantity divided by the number of units demanded.

### III. EQUIPMENT-RELATED ITEMS

As previously defined, an item is said to be an ER item when it is on the ICP candidate file. The AS 36 ER load list candidate items include both items with historical demand and items installed on the supported submarines but with no historical demand.

Currently, the goal for the ER portion of the conventional submarine tender load list is a net units effectiveness of 90%. The current model utilizes a range cut to achieve the desired range and then computes depth using a variable protection model designed to meet an essentiality-weighted units effectiveness goal at minimum cost. For items with a demand history, demand is used as a measure of essentiality. For items with no historical demand, essentiality is based

on the vital/nonvital MEC. Load list items with no historical demand are constrained to a maximum quantity of 50 and a maximum total cost of \$100, unless the unit price for the item is greater than \$100. If the unit price for an item with no historical demand is greater than \$100, the item is constrained to a quantity of one.

This study evaluates alternative range and depth criteria. The Normal distribution is compared with the Poisson distribution and combined Normal-Poisson distributions to see which distribution describes the demand of ER items most accurately. Various range criteria are compared to see which one gives the desired range most efficiently. An effectiveness goal based on predicted demand-weighted units short is compared to effectiveness goals based on predicted demand-weighted requisitions short, units short, requisitions short, and the currently used essentiality-weighted units short.

A. RANGE CRITERIA AND PROBABILITY DISTRIBUTIONS. The current model uses a range cut based on predicted AQD to obtain the range desired for the conventional submarine tender load list. For the AS 36 tender load list, a range cut based on a predicted AQD of .5 was used (a .5 AQD range cut). This means that only load list candidate items which had at least two units of demand predicted per year were

placed on the load list.

An alternative technique for obtaining the desired range makes use of an optimization model to maximize gross effectiveness subject to a range goal or dollar value goal. This technique should be more cost-effective than using a range cut based on predicted AOD.

COMSUBLANT (Commander, Submarine Force, Atlantic) representatives advised that the newer conventional submarine tenders can accommodate about 25,000 ER items, whereas the older conventional submarine tenders can only accommodate about 18,000 ER items. Thus, tests were made at both ranges.

Since the comparison of the range cut model and the optimization model may vary significantly based on the demand probability distribution assumption, both models were tested with both the Normal and the Poisson distribution. For all the test loads created in this segment of the ER study, an effectiveness goal that minimized demand-weighted units short was used.

TABLE I compares the Normal and Poisson probability distributions for the range cut model. Both test loads were based on a .5 AOD range cut and a 90% net units effectiveness goal. TABLE I shows that the Normal distribution (Line 1) produced about 20% better units effectiveness, about 7% better requisitions effectiveness, and the same range

effectiveness. (Range effectiveness is the same for both distributions because the items carried in both runs were identical.)

TABLE I  
COMPARISON OF PROBABILITY DISTRIBUTIONS  
(RANGE CUT MODEL)

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal	17,152	2.05M	72.4%	59.5%	61.6%
2	Poisson	17,152	1.87M	52.4%	52.7%	61.6%

NOTE: Models based on current .5 AQD range cut and 90% net units effectiveness goal

TABLE II again compares a load list built using the Normal distribution to a load list built using the Poisson distribution. However, in this comparison the optimization model is used instead of the range cut model. The load list built using the Normal distribution (Line 1) had about 20% better units effectiveness, 10% better requisitions effectiveness and about 7% better range effectiveness.

For this optimization model, the Normal distribution more closely achieved the predicted effectiveness. However,

the load list built using the Normal distribution contained about 50% more items but only resulted in about 7% better range effectiveness. Thus, the Poisson distribution may be more accurate in obtaining the desired range. Consequently, it was decided to evaluate load lists built using a combination of the Normal distribution and the Poisson distribution.

TABLE II  
COMPARISON OF PROBABILITY DISTRIBUTIONS  
(OPTIMIZATION MODEL)

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal	24,187	.57M	73.6%	58.3%	57.2%
2	Poisson	15,524	.45M	53.7%	48.1%	50.0%

NOTE: Models based on 80% gross units effectiveness goal which is the gross predicted for the current model

Two different combination Normal-Poisson distributions were used. The first combined distribution was based on predicted AQD. For items with a predicted AQD less than or equal to one, the Poisson distribution was used. For items with a predicted AQD greater than one, the Normal distribution was

used. This combined distribution will be referred to as the Normal-Poisson-size distribution.

The second combined distribution was based on historical demand. The Normal distribution was used for items with historical demand and the Poisson distribution was used for items with no historical demand. This combined distribution will be referred to as the Normal-Poisson-demand distribution.

TABLE III compares these two new test load lists to the two load lists built using the Normal distribution. These four load lists were found to have comparable units effectiveness and requisitions effectiveness. The load list built using the Normal distribution with a range cut (Line 1) had the best requisition effectiveness, but the load list built using the Normal-Poisson-size distribution and the optimization model to control the range (Line 3) had the best units effectiveness.

TABLE III  
COMPARISON OF RANGE CRITERIA AND PROBABILITY  
DISTRIBUTIONS

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal -- Range Cut	17,152	2.05M	72.4%	59.5%	61.6%
2	Normal -- Optimization	24,187	.57M	73.6%	58.3%	57.2%
3	Normal-Poisson -Size -- Optimization	18,308	.58M	74.1%	56.6%	54.2%
4	Normal-Poisson -Demand -- Optimization	18,098	.60M	73.1%	56.7%	55.2%

NOTE: All loads provide 80% predicted gross units effectiveness

Although the load lists based on the optimization model produced lower requisition effectiveness, these loads were inexpensive relative to the range cut model. Therefore, the predicted gross units effectiveness goal was raised from 80% to 85% in an attempt to increase effectiveness while still holding the dollar value below the range cut model. Three different test loads were built using the optimization

model and an 85% gross effectiveness goal. The probability distributions used for these load lists were the two combined Normal-Poisson distributions and the Normal distribution.

TABLE IV compares these three load lists to the .5 AQD range cut model. Although the load list built using the Normal distribution with an 85% goal (Line 4) had the best overall effectiveness, its range was too large based on current guidance. Thus, a load list using the Normal distribution and a gross effectiveness goal of 80% is also shown. TABLE IV shows that both combined Normal-Poisson distributions (Lines 2 and 3) produce load lists with better overall effectiveness than the range cut model (Line 1), greater range, but about one-third the cost.

TABLE IV  
COMPARISON OF RANGE CRITERIA AND PROBABILITY  
DISTRIBUTIONS

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal -- Range Cut	17,152	2.05M	72.4%	59.5%	61.6%
2	Normal-Poisson -Size -- Optimization (85% gross)	24,466	.74M	75.0%	63.0%	62.0%
3	Normal-Poisson -Demand -- Optimization (85% gross)	21,852	.68M	74.2%	61.4%	60.8%
4	Normal -- Optimization (85% gross)	34,215	.76M	75.5%	66.2%	66.9%
5	Normal -- Optimization (80% gross)	24,187	.57M	73.6%	58.3%	57.2%

Further analysis revealed that both optimization models with Normal-Poisson distributions stocked more historical demand items than the range cut model with the Normal distribution. The load list built using the Normal-Poisson-demand distribution contained 5,890 items with historical

demand, compared to 5,552 items for the Normal-Poisson-size distribution and 4,726 for the Normal distribution with a range cut.

In summary, TABLE IV shows that significant dollar savings can be achieved with no significant decrease in effectiveness by using an optimization model with either of the Normal-Poisson distributions in lieu of a range cut model. However, these models do increase item range. From TABLE III, it is seen that these same models with a reduced gross effectiveness goal, produce loads with the same range and units effectiveness as the range cut model, significant dollar savings, but lower requisition and range effectiveness.

The next section will further analyze the optimization model with alternative effectiveness goals in an attempt to meet all current effectiveness measures without significantly increasing range.

#### B. EFFECTIVENESS GOALS.

1. Essentiality-Weighted Model. The models discussed in Section A all had an effectiveness goal based on average demand-weighted units short. The current model has an effectiveness goal based on essentiality-weighted units short. For items with a demand history, demand is used as a measure of essentiality. For items with no historical demand, essentiality is based on the vital/nonvital MEC. TABLE V

compares a load list using these current criteria to a load list using an effectiveness goal based on demand-weighted units short. Both these loads were based on the current .5 AQD range cut and 90% net units effectiveness goal. The load list built using the current essentiality-weighted units short model (Line 2) performed better and was more expensive.

TABLE V

COMPARISON OF EFFECTIVENESS GOALS  
USING THE NORMAL DISTRIBUTION  
(RANGE CUT MODEL)

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Demand-Weighted Units Short	17,152	2.05M	72.4%	59.5%	61.6%
2	Essentiality-Weighted Units Short (Current)	17,152	2.15M	74.2%	62.4%	61.6%

NOTE: Models based on current .5 AQD range cut and 90% net units effectiveness goal

A load list was built using the essentiality-weighted units short optimization model to control range and depth.

This model with a gross units effectiveness goal of 80% resulted in a load list which had a range of over 60,000 items. Thus, the essentiality-weighted model must be constrained with a range cut. However, it was shown earlier that a range cut model was not as cost-effective as the optimization model.

It was observed that over 97% of the candidate items had the highest possible MEC value. This makes the credibility of using the current essentiality-weighted units short model questionable. Thus, it is necessary to examine alternative performance goals.

2. Alternative Optimization Models. Alternative optimization models that minimize units short, demand-weighted units short, requisitions short, and demand-weighted requisitions short are evaluated in the following paragraphs.

Each of these optimization models results in a slightly different computation of the item protection level, as shown below:

. Units Short Model

$$\text{Protection Level} = 1 - \lambda (\text{Unit Price})$$

. Demand-Weighted Units Short Model

$$\text{Protection Level} = 1 - \frac{\lambda (\text{Unit Price})}{\text{AQD}}$$

. Requisitions Short Model

$$\text{Protection Level} = 1 - \lambda (\text{Unit Price})(\text{Avg Reqn Size})$$

. Demand-Weighted Requisitions Short Model

$$\text{Protection Level} = 1 - \frac{\lambda(\text{Unit Price})(\text{Avg Reqn Size})}{\text{AQD}}$$

where

$\lambda$  (lambda) = control parameter to achieve  
specified effectiveness

TABLE VI compares various optimization models using the Normal-Poisson-size distribution. The Units Short Model with an 80% predicted gross units effectiveness goal (Line 2) had about the same performance as the current model (Line 1), but produced an apparent excessive range (33,842 items). The model that minimizes units short with a 25,000 item range goal (Line 3) had significantly lower effectiveness than the current model. The model that minimizes requisitions short with an 80% predicted gross requisitions effectiveness goal (Line 4) had both too large a range and significantly lower effectiveness than the current model. The model that minimizes demand-weighted units short with an 85% predicted gross units effectiveness goal (Line 5) had slightly better effectiveness than the current model, but had too large a range for the older tenders. The same model with an 80% predicted gross units effectiveness goal (Line 6) had an

TABLE VI

COMPARISON OF EFFECTIVENESS GOALS  
NORMAL-POISSON-SIZE DISTRIBUTION  
(OPTIMIZATION MODEL)

ER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Current Model (Normal distribution, Range Cut, Essentiality-Weighted Units Short)	17,152	2.15M	74.2%	62.4%	61.6%
2	Units Short (80% gross)	33,842	.54M	72.6%	63.5%	66.0%
3	Units Short (25,000 items)	25,283	.36M	69.4%	54.7%	56.2%
4	Requisitions Short (80% gross)	33,158	.44M	43.8%	55.4%	60.4%
5	Demand-Weighted Units Short (85% gross)	24,466	.74M	75.0%	63.0%	62.0%
6	Demand-Weighted Units Short (80% gross)	18,308	.58M	74.1%	56.6%	54.2%
7	Demand-Weighted Requisitions Short (80% gross)	24,022	.60M	72.9%	60.4%	59.8%

acceptable range for the older tenders, but had lower

requisitions effectiveness and range effectiveness than the current model. The model that minimizes demand-weighted requisitions short with an 80% predicted requisitions effectiveness goal (Line 7) had slightly lower performance than the current model and an excessive range for the older tenders.

A comparison of the demand-weighted requisitions short model (80% gross) to both demand-weighted units short models (80% gross and 85% gross) reveals the following:

. The models based on an 80% gross effectiveness goal (Lines 6 and 7) had approximately the same dollar value. The units short model (Line 6) produced about 1% higher units effectiveness; however, the requisitions short model (Line 7) produced 4% higher requisitions effectiveness and 6% higher range effectiveness.

. The 80% requisitions short model (Line 7) and the 85% units short model (Line 5) produced about the same range, with the units short model costing \$.14M more and producing about 2% higher effectiveness for every measure.

. The 85% units short model (Line 5) is the only model that achieves the same effectiveness (units, requisitions, and range) as the current model (Line 1).

In summary, the dollar value of the conventional submarine

tender load list can be reduced 66% to 73% by using the optimization model which minimizes demand-weighted units short with either of the Normal-Poisson probability distributions. This model would have no impact on units effectiveness. However, it would decrease requisitions and range effectiveness unless the range were increased about 40% from 17,152 to 24,466 items. It is recommended that this model be considered for conventional submarine tender load lists, since it is felt that units effectiveness is the most complete measure of the effectiveness of both range and depth decisions. Range effectiveness reflects only the selection of which items to stock. Requisitions effectiveness reflects both range and depth decisions, but is somewhat distorted since partially filled requisitions are counted as satisfied.

#### IV. NONEQUIPMENT-RELATED ITEMS

An item is said to be an NER item when it has historical demand, but is not on the ICP candidate file. Currently, the goal for the NER portion of the conventional submarine tender load list is a net units effectiveness of 90%. The current model utilizes a .5 AQD range cut to achieve the desired range and then computes depth using a variable protection model designed to minimize demand-weighted units short and assumes a Normal demand distribution.

This study evaluates alternative range and depth criteria. The Normal distribution will be compared with the Poisson distribution and a combined Normal-Poisson distribution to see which distribution describes the demand of the NER items most accurately. Various range criteria will be compared to see which one will give the desired range most efficiently. A depth criterion based on predicted demand-weighted units short will be compared to depth criteria based on predicted demand-weighted requisitions short, units short, and requisitions short.

A. PROBABILITY DISTRIBUTIONS. The current conventional submarine tender load list model for NER items assumes a Normal demand distribution.

Test load lists were built using the Normal distribution and the Poisson distribution. As in the ER segment (Section III.A), a load list was also built using the Normal-Poisson-size distribution. (If an item had a predicted AQD of one or less the Poisson distribution was used; otherwise, the Normal distribution was used to describe the demand for the item.) The Normal-Poisson-demand distribution discussed in Section III.A uses the Normal distribution for items with historical demand and uses the Poisson distribution for items with no demand. All NER items by definition have historical demand and, therefore, use the Normal distribution.

Thus, the Normal-Poisson-demand distribution will not be discussed separately.

For the test loads created in this segment of the NER study, an optimization model that minimizes demand-weighted requisitions short was used to control range and depth. An 87% gross effectiveness goal was used for all NER test loads, since an 87% gross effectiveness corresponded to the 90% net effectiveness for the current model.

TABLE VII shows that the NER portion of the load list built using the Normal distribution (Line 1) had about 25% better units effectiveness, about 11% better requisitions effectiveness, and about 1% better range effectiveness than the Poisson distribution (Line 2). The Normal distribution (Line 1) and the Normal-Poisson-size (Line 3) distribution had essentially the same performance. The reason for this is that: (1) all NER items with a predicted AQD of .5 or less were deleted from the load list candidate file unless an override was assigned; and (2) for AQDs of .5 to 1.0 with the allowed range of protection values (1% to 99%), the Normal and Poisson usually produce the same quantity.

TABLE VII  
COMPARISON OF PROBABILITY DISTRIBUTIONS  
(OPTIMIZATION MODEL)

NER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal	3,053	235K	86.1%	88.1%	93.6%
2	Poisson	2,983	120K	61.3%	76.6%	92.2%
3	Normal-Poisson -Size	2,979	222K	85.6%	87.2%	92.3%

B. RANGE CRITERIA. The current conventional submarine tender load list model uses a .5 AQD range cut to obtain the desired range. TABLE VIII compares load lists using this criterion to load lists based on an optimization model to control range. Both the Normal distribution and the Normal-Poisson-size distribution were used along with an effectiveness goal that minimizes demand-weighted requisitions short.

TABLE VIII  
COMPARISON OF RANGE CRITERIA  
NER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Normal -- Optimization	3,053	235K	86.1%	88.1%	93.6%
2	Normal -- Range Cut	3,391	264K	85.5%	89.6%	100.0%
3	Normal-Poisson -Size -- Optimization	2,979	222K	85.6%	87.2%	92.3%
4	Normal-Poisson -Size -- Range Cut	3,391	249K	84.7%	89.0%	100.0%

TABLE VIII shows that the load lists built using a range cut (Lines 2 and 4) had a higher range and dollar value, slightly lower units effectiveness, slightly higher requisitions effectiveness, and significantly higher range effectiveness. In fact, the range cut model stocked every candidate item. However, as described earlier, all NER items with a predicted AQD of .5 or less or a total two year demand frequency of one were deleted from the candidate file unless there was a mandatory or minimum override assigned. On the

AS 36, 6,198 items were deleted by these criteria. Of these, 429 were demanded during the evaluation period accounting for 547 requisitions and 5,695 units.

In summary, an optimization model would produce slightly higher units effectiveness and slightly lower requisitions effectiveness than the range cut model with fewer items and lower dollar value.

C. EFFECTIVENESS GOALS. The current conventional submarine tender load list model for NER items minimizes demand-weighted units short. This model is compared to models that minimize demand-weighted requisitions short, units short, and requisitions short. These models are evaluated both using the .5 AQD range cut model and an optimization model.

The item protection levels for the different models are:

- . Demand-Weighted Units Short

$$\text{Protection Level} = 1 - \frac{\lambda (\text{Unit Price})}{\text{AQD}}$$

- . Demand-Weighted Requisitions Short

$$\text{Protection Level} = 1 - \frac{\lambda (\text{Unit Price}) (\text{Avg Reqn Size})}{\text{AQD}}$$

- . Units Short

$$\text{Protection Level} = 1 - \lambda (\text{Unit Price})$$

- . Requisitions Short

$$\text{Protection Level} = 1 - \lambda (\text{Unit Price}) (\text{Avg Reqn Size})$$

where

$\lambda$  (lambda) is a control parameter to achieve  
specified effectiveness value

TABLE IX compares the various effectiveness goals using a range cut model. TABLE IX shows that the load list built using the demand-weighted requisitions short goal and the Normal distribution (Line 2) had about 4% better units effectiveness and about 15% better requisitions effectiveness than the current model (Line 1). TABLE IX also shows that the load lists built using the demand-weighted requisitions short goal (Lines 2 and 3) had better units effectiveness and requisitions effectiveness than the load lists based on units short (Line 5) or requisitions short (Line 4) goals. However, the demand-weighted requisitions short model (Lines 2 and 3) is also the most expensive.

TABLE IX

COMPARISON OF EFFECTIVENESS GOALS  
(RANGE CUT MODEL)

NER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Demand-Weighted Units Short-Normal distribution (Current Model)	3,391	199K	81.7%	74.4%	100.0%
2	Demand-Weighted Requisitions Short-Normal distribution	3,391	264K	85.5%	89.6%	100.0%
3	Demand-Weighted Requisitions Short-Normal-Poisson-size distribution <sup>1</sup>	3,391	249K	84.7%	89.0%	100.0%
4	Requisitions Short-Normal-Poisson-size distribution <sup>1</sup>	3,391	165K	75.9%	87.2%	100.0%
5	Units Short-Normal-Poisson-size distribution <sup>1</sup>	3,391	152K	78.7%	76.9%	100.0%

<sup>1</sup>Although a different demand distribution was used for these runs, TABLE VII shows that the Normal-Poisson-size distribution will result in load lists with less than 1% lower effectiveness than the Normal distribution.

TABLE X compares the same effectiveness goals as TABLE IX. However, for the load lists compared in TABLE X, range was controlled by means of an optimization model. Results are similar to those shown in TABLE IX for the range cut model. The demand-weighted requisitions short model (Lines 2 and 3) outperformed all other models, but was also the most expensive.

Line	Model	Cost	Effectiveness	Range
1	Demand-Weighted Short-Range Normal Distribution Item (Current Model)	100.00	85.00	100.00
2	Demand-Weighted Requisitions Short-Normal Distribution	100.00	85.00	100.00
3	Demand-Weighted Requisitions Short-Normal- Range-Dist	100.00	85.00	100.00
4	Requisitions Short-Normal- Range-Dist Distribution	100.00	85.00	100.00
5	Requisitions Normal-Poisson Dist	100.00	85.00	100.00

Although a different demand distribution was used for these items, TABLE VII shows that the Normal-Poisson-Range-Dist will result in load lists with less than 1% lower effectiveness than the Normal Distribution.

TABLE X  
COMPARISON OF EFFECTIVENESS GOALS  
(OPTIMIZATION MODEL)

NER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Demand-Weighted Units Short-Normal distribution	1,722	145K	81.2%	61.3%	59.2%
2	Demand-Weighted Requisitions Short-Normal distribution	3,053	235K	86.1%	88.1%	93.6%
3	Demand-Weighted Requisitions Short-Normal-Poisson-size distribution <sup>1</sup>	2,979	222K	85.6%	87.2%	92.3%
4	Requisitions Short-Normal-Poisson-size distribution	3,150	121K	75.8%	86.0%	94.8%
5	Units Short-Normal-Poisson-size distribution <sup>1</sup>	2,619	96K	78.2%	70.2%	79.9%

<sup>1</sup>Although a different demand distribution was used for these runs, TABLE VII shows that the Normal-Poisson-size distribution will result in load lists with less than 1% lower effectiveness than the Normal distribution.

TABLE XI compares the demand-weighted requisitions short models from TABLES IX and X with the current NER model. A comparison of the optimized range model (Lines 1 and 2) with the range cut model (Lines 3 and 4) shows that the optimized range model produces higher units effectiveness at a lower cost. This is consistent with the findings of Section IV.B. It is also noted that the demand-weighted requisitions short optimization model (Lines 1 and 2) increased dollar value only \$23K to \$36K over the current model (Line 5), while improving units effectiveness by 4% and requisitions effectiveness about 13%. Accordingly, it is recommended that the conventional submarine NER model use a demand-weighted requisitions short model with an optimized range determination.

TABLE XI  
COMPARISON OF DEMAND-WEIGHTED REQUISITIONS  
SHORT MODELS AND CURRENT MODEL

NER ITEMS

LINE	ALTERNATIVE	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
1	Demand-Weighted Requisitions Short-Normal distribution -- Optimization	3,053	235K	86.1%	88.1%	93.6%
2	Demand-Weighted Requisitions Short-Normal-Poisson-size distribution -- Optimization	2,979	222K	85.6%	87.2%	92.3%
3	Demand-Weighted Requisitions Short-Normal distribution -- Range Cut	3,391	264K	85.5%	89.6%	100.0%
4	Demand-Weighted Requisitions Short-Normal-Poisson-size distribution -- Range Cut	3,391	249K	84.7%	89.0%	100.0%
5	Current Model (Demand-Weighted Units Short-Normal distribution)	3,391	199K	81.7%	74.4%	100.0%

## V. COMPARISON WITH AS(FBM) TENDER LOAD LIST

Reference 1 evaluated alternative criteria for the FBM submarine tender load list and recommended certain changes to produce a more cost-effective load. TABLE XII compares the recommendations of that study with the recommendations of the conventional submarine tender study. Two criteria evaluated in this study were not evaluated in reference 1. Specifically, these are the use of the Normal-Poisson-demand distribution for ER items and the use of a range cut for NER items. These criteria are evaluated for the FBM load list in APPENDIX D and the results are reflected in TABLE XII.

TABLE XII shows that the model recommendations for the FBM load list are generally valid for the conventional load list. The exceptions are summarized below:

. For the conventional submarine tender load list ER items, the Normal-Poisson-size distribution and the Normal-Poisson-demand distribution produced similar results; for the FBM submarine tender load list ER items, the Normal-Poisson-size distribution clearly performed the best.

. For the FBM load list ER items, the demand-weighted units short model and the demand-weighted requisitions short model performed almost identically; for the conventional load list ER items this was not the case. For the conventional

TABLE XII  
COMPARISON BETWEEN FBM LOAD LIST AND  
 CONVENTIONAL SUBMARINE LOAD LIST RECOMMENDATIONS

	FBM	CONVENTIONAL
<b>ER:</b>		
Range Criteria	Optimization Model	Optimization Model
Effectiveness Goal	Demand-Weighted Units or Demand-Weighted Requisitions	Demand-Weighted Units
Distribution	Normal-Poisson-Size	Normal-Poisson-Size or Normal-Poisson- Demand
<b>NER:</b>		
Range Criteria	Optimization Model	Optimization Model
Effectiveness Goal	Demand-Weighted Requisitions	Demand-Weighted Requisitions
Distribution	Normal or Normal- Poisson-Size	Normal or Normal- Poisson-Size

load list ER items the demand-weighted requisitions short model performed better under equal price conditions, but the demand-weighted units short model performed better under equal range conditions. The demand-weighted units short model was recommended because of the criticality of the range constraint.

A single model for both conventional and FBM submarine tenders could be obtained by selecting the TABLE XII criteria common to both tenders. Specifically, for ER items, an optimization model that minimizes demand-weighted units short and uses a Normal-Poisson-size distribution to describe item demand would accommodate both FBM and conventional submarine tenders. For NER items, an optimization model that minimizes demand-weighted requisitions short and uses a Normal or Normal-Poisson-size distribution to describe item demand would accommodate both submarine tenders.

## VI. SUMMARY AND RECOMMENDATIONS

A. EQUIPMENT-RELATED ITEMS. Currently, the Normal distribution is used to describe demand for ER items. This study evaluated use of the Normal, the Poisson, and combined Normal-Poisson distributions. The first combined distribution evaluated, which was called the Normal-Poisson-size distribution, uses the Poisson distribution for items with a predicted AQD of one or less and uses the Normal distribution for items with a predicted AQD greater than one. The second combined distribution evaluated, which was called the Normal-Poisson-demand distribution, uses the Normal distribution for items with historical demand and the Poisson distribution for items with no historical demand. It was shown that either of these

Normal-Poisson distributions will produce better support than the Normal distribution or the Poisson distribution.

A range cut based on predicted AQD is now being used to obtain the desired range for the ER portion of the load list. This technique was compared with a model that optimizes both range and depth. The comparison revealed that an optimization model is more cost-effective.

An effectiveness goal based on minimizing essentiality-weighted units short is currently being used. For items with a demand history, demand is used as a measure of essentiality. For items with no historical demand, essentiality is based on vital/nonvital MEC. Models minimizing units short, demand-weighted units short, requisitions short, demand-weighted requisitions short, and the current model were evaluated. This study showed that the current essentiality-weighted units short model produces unacceptably high ranges when used without a range cut. It also showed that over 97% of the items are coded with the highest MEC possible, thus making the desirability of using such a model questionable. When an optimization model is used to control range, the demand-weighted units short or demand-weighted requisitions short model performs best.

Comparing the demand-weighted requisitions short model to the demand-weighted units short model, it is noted that: (1) the requisitions short model generally performs better than the

units short model for the same dollars; but (2) the units short model performs better for the same range of items. Both the demand-weighted models significantly decrease the dollar value as compared to the current load. However, since the range constraint is critical on the older conventional submarine tenders, the demand-weighted units short model is preferred.

In summary, the dollar value of the conventional submarine tender load list can be reduced 66% to 73% by using an optimization model minimizing demand-weighted units short with either of the Normal-Poisson probability distributions. This model would have no impact on units effectiveness. However, to maintain the current requisition and range effectiveness, it would be necessary to increase range about 40%. Units effectiveness is considered the most complete measure of the effectiveness of both range and depth decisions, as range effectiveness reflects only the selection of which items to stock, and requisitions effectiveness reflects both range and depth decision but is distorted since partially filled requisitions are counted as satisfied.

These findings were compared to the results of a similar study for FBM submarine tenders and found consistent. Therefore, a common model for FBM and conventional submarine tenders is recommended. Specifically, it is recommended that

equipment-related item computations be based on an optimization model that minimizes demand-weighted units short and that a combined Normal-Poisson distribution based on the size of the AQD be used to describe item demand. It is noted that the current FBM model is an optimization model that minimizes demand-weighted requisitions short and uses the recommended demand distribution.

B. NONEQUIPMENT-RELATED ITEMS. The Normal distribution is currently used to describe demand for NER items. This study evaluated use of the Normal, the Poisson and a combined Normal-Poisson distribution, where the Poisson was used for items with a predicted AQD of one or less and the Normal was used for all other items. This combined Normal-Poisson distribution was called the Normal-Poisson-size distribution. The Normal distribution and the Normal-Poisson-size distribution produced similar results, both much better than the Poisson distribution.

A range cut based on predicted AQD is now being used to obtain the desired range for the NER portion of the load list. This technique was compared with a model that optimizes both range and depth. The optimization model produced approximately the same units and requisitions effectiveness as the current model with fewer items and lower dollar value.

The current NER model minimizes demand-weighted units

short. Alternative models minimizing units short, requisitions short, and demand-weighted requisitions short were also evaluated. The model that minimizes demand-weighted requisitions short consistently outperformed the other models.

These findings were compared to the results of a similar study for FBM submarine tenders and found consistent. Therefore, a common model for FBM and conventional submarine tenders is recommended. Specifically, it is recommended that nonequipment-related item computations be based on an optimization model that minimizes demand-weighted requisitions short with either a Normal or combined Normal-Poisson distribution to describe item demand. It is noted that the current FBM model is an optimization model that minimizes demand-weighted requisitions short and uses a combined Normal-Poisson distribution based on the size of the AQD. Since there is no significant difference between the results obtained from the Normal and from the combined Normal-Poisson, the combined distribution is preferred to eliminate reprogramming effort.

**APPENDIX A: REFERENCES**

1. FMSO Operations Analysis Department Report 127 -  
FBM Load List Study of 31 December 1976

## APPENDIX B: EQUIPMENT-RELATED CANDIDATE ITEM STATISTICS

A two year demand base was used to compute the predicted AQD for the AS 36 tender load list candidate items. If an item had demand within this two year period, the predicted AQD for the item is equal to the total demand during the two year period divided by eight. If an item did not have demand within this two year period, its predicted AQD is set equal to the BRP (Best Replacement Factor) for the item times the supported item population divided by four. The population is comprised of two elements: that which can be installed by the supported submarine and that which can be installed only at the tender.

If an item had demand within the two year demand base period, the average requisition size for the item is set equal to the total demands during the two year period divided by the total demand frequency during the two year period. If an item did not have demand during the two year period, its average requisition size is set equal to one, unless the item had a predicted AQD of zero and no mandatory or minimum technical override. If an item had a predicted AQD of zero and no mandatory or minimum technical override, its average requisition size is set equal to zero. About 89% of the AS 36 ER load list candidate items had no demand within

the two year demand base period.

Statistics on predicted AQD, average requisition size, and unit prices for the AS 36 ER load list candidate items follow.

PREDICTED AVERAGE QUARTERLY DEMAND FOR ER ITEMS

<u>PREDICTED AQD &lt;</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
0.00	8,986	9.69
0.05	43,395	46.80
0.10	52,962	57.12
0.20	64,432	69.49
0.30	70,656	76.20
0.40	74,120	79.94
0.50	76,617	82.63
1.00	82,819	89.32
1.50	85,481	92.19
2.00	86,791	93.61
3.00	88,390	95.33
4.00	89,255	96.26
5.00	89,863	96.92
10.00	91,205	98.38
20.00	91,977	99.20
30.00	92,233	99.48
40.00	92,345	99.60
50.00	92,441	99.70
100.00	92,570	99.84
1000.00	92,708	99.98
10000.00	92,719	100.00

AVERAGE REQUISITION SIZE FOR ER ITEMS

<u>REQUISITION SIZE ≤</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
0.0	8,730	9.42
1.0	87,056	93.90
1.5	87,703	94.60
2.0	89,126	96.13
3.0	89,894	96.96
4.0	90,464	97.57
5.0	90,976	98.12
10.0	91,864	99.08

There were 855 items (.92%) with an average requisition size greater than 10.0.

UNIT PRICE FOR ER ITEMS

<u>UNIT PRICE ≤</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
.25	9,895	10.67
.50	15,904	17.15
1.00	24,344	26.26
5.00	47,346	51.06
10.00	56,385	60.81
100.00	78,598	84.77
1000.00	89,807	96.86
10000.00	92,441	99.70

There were 278 items (.3%) with a unit price greater than \$10,000.

### APPENDIX C: NONEQUIPMENT-RELATED CANDIDATE ITEM STATISTICS

A two year demand base was used to compute the predicted AQD for the AS 36 tender load list candidate items. The predicted AQD for an item is equal to the total demand for the item during the two year period divided by eight.

The average requisition size of an item equals the total demands during the two year period divided by the total demand frequency during the two year period.

Statistics on predicted AQD, average requisition size, and unit prices for the AS 36 NER load list candidate items follow.

#### PREDICTED AVERAGE QUARTERLY DEMAND FOR NER ITEMS

<u>PREDICTED AQD ≤</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
1.00	738	21.47
1.50	1,182	34.38
2.00	1,461	42.50
3.00	1,868	54.33
4.00	2,115	61.52
5.00	2,294	66.72
10.00	2,724	79.23
20.00	3,029	88.10
30.00	3,159	91.88
40.00	3,219	93.63
50.00	3,257	94.74
100.00	3,351	97.47
1000.00	3,428	99.71
10000.00	3,438	100.00

AVERAGE REQUISITION SIZE FOR NER ITEMS

<u>REQUISITION SIZE ≤</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
1.0	53	1.54
1.5	320	9.31
2.0	763	21.19
3.0	1,400	40.72
4.0	1,755	51.05
5.0	1,994	58.00
10.0	2,606	75.80

There were 832 items (24.20%) with an average requisition size greater than 10.0.

UNIT PRICE FOR NER ITEMS

<u>UNIT PRICE ≤</u>	<u>CUMULATIVE NR ITEMS</u>	<u>CUMULATIVE %</u>
.25	362	10.53
.50	715	20.80
1.00	1,191	34.64
5.00	2,330	67.77
10.00	2,705	78.68
100.00	3,348	97.38
1000.00	3,422	99.54
10000.00	3,438	100.00

APPENDIX D: MODEL CRITERIA NOT TESTED IN PREVIOUS FBM STUDY

1. Demand Distribution for ER Items. The Normal-Poisson-demand distribution was not evaluated for ER items in the FBM load list study (Operations Analysis Department Report 127). This distribution makes use of the Normal distribution for items with demand history and the Poisson distribution for items with no demand history. The recommended distribution in the FBM load list study was the Normal-Poisson-size distribution. This distribution uses the Poisson distribution for items with a predicted AQD less than or equal to one and the Normal distribution otherwise. These two Normal-Poisson distributions are compared in TABLE I using AS 31 data.

TABLE I  
DEMAND DISTRIBUTION-ER ITEMS

	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
Normal-Poisson-Size	25,907	1.86M	65.5%	78.4%	87.4%
Normal-Poisson-Demand	26,369	1.13M	60.2%	78.1%	88.7%

The load list built using the Normal-Poisson-size distribution had about 5% better units effectiveness, about the same

requisitions effectiveness and about 1% lower range effectiveness. However, it also cost over 1.5 times as much as the load list built using the Normal-Poisson-demand distribution. Unless cost reduction is a major consideration, the Normal-Poisson-size distribution is recommended.

2. Range Criteria for NER Items. The range cut model was not evaluated for NER items in the FBM load list study (Operations Analysis Department Report 127). The range cut model is compared in TABLE II to the currently used optimization model using the AS 31 as the test tender.

TABLE II

RANGE CRITERIA-NER ITEMS

	RANGE	DOLLAR VALUE	GROSS UNITS EFF	GROSS REQNS EFF	RANGE EFF
Optimization Model	1,777	142K	70.6%	70.2%	92.7%
Range Cut Model	1,912	200K	70.6%	70.5%	95.3%

The load list built using the range cut model cost almost 1.5 times as much as the load list built using the optimization model, but performs about the same. The optimization model is, therefore, recommended as most cost-effective.

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13. ABSTRACT  
This study evaluates alternative techniques for computing conventional submarine tender load lists, given specified performance goals. Areas that are evaluated include: (1) the use of alternative demand distributions; (2) the use of alternative techniques for controlling range; and (3) the use of alternative optimization models. Alternatives are evaluated separately for equipment-related and nonequipment-related items. The various techniques are evaluated using actual submarine demand data. The models are evaluated in terms of units effectiveness, requisitions effectiveness, and range effectiveness. A common model is recommended for computing conventional and FBM (Fleet Ballistic Missile) submarine tender load lists.

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