REVISED BRF COMPUTATION STUDY

OPERATIONS ANALYSIS DEPARTMENT

NAVY FLEET MATERIAL SUPPORT OFFICE

Mechanicsburg, Pennsylvania 17055

Report 163

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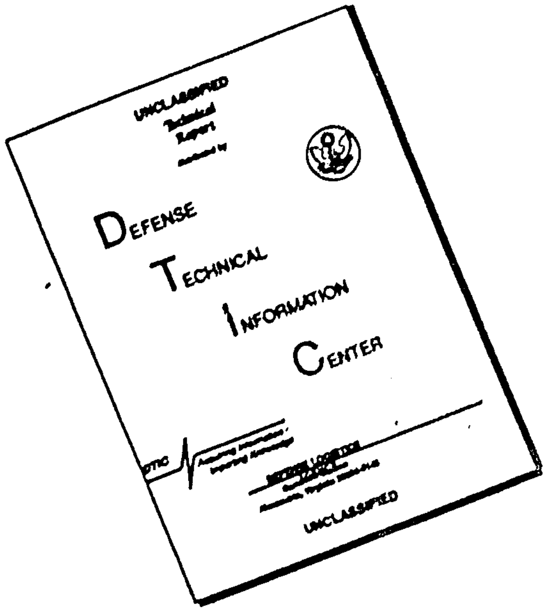

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REPORT 163

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ABSTRACT

The Navy uses an item's Best Replacement Factor (BRF) to estimate allowance requirements for items in the supply system. Each year BRFs are updated to reflect the latest usage and population data available. The current system computes a weighted average between the most recent BRF and the latest year of usage and population data to produce each item's new BRF. An alternative proposed method computes BRFs as the ratio of an item's total lifetime usage to the sum of the item's yearly average populations. A third method of computing BRFs which utilizes an Adaptive-Response-Rate Single Exponential Smoothing (ARRSES) procedure is also considered. These methods of computing BRFs are compared to determine which produces the most accurate estimates of future usage. Additionally, BRFs produced by the most promising methods are used to build a series of Coordinated Shipboard Allowance Lists (COSALs) for three test ships. The COSALs are compared and differences in range, cost, stock churn and supply effectiveness caused by the different types of BRFs are identified, quantified and evaluated.

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EXECUTIVE SUMMARY

1. Introduction. An item's Best Replacement Factor (BRF) is the annual rate, per unit of installed population, at which the item is replaced because of failure or maintenance actions. Each year the BRF is updated to reflect the latest reported usage. A new BRF is produced by computing a smoothed or weighted average between the item's current BRF and the item's usage per unit population that was experienced during the last year.

A review of several years of updates indicate that there are continuing problems with the current system. The statistics show that the majority of BRFs are too large when compared to actual usage. At the same time, the current system produces BRFs for very slow-moving items which are too erratic. Inaccurate and changing BRFs affect Coordinated Shipboard Allowance Lists (COSALs) in areas such as stock churn, which is too high, and supply effectiveness, which is too low.

This study tested and evaluated two alternative ways of computing BRFs to determine if either could produce a more accurate BRF. One procedure, called the Ratio Method, computes BRFs as the ratio of an item's total lifetime usage to the sum of the item's yearly average populations. The other new method is an Adaptive-Response-Rate Single Exponential Smoothing (ARRSES) procedure. ARRSES computes a smoothed average between the latest BRF and the most recent usage just as the current system does. The two procedures differ in the way each assigns values to the smoothing weight. The current system uses subjectively determined values while the ARRSES system computes them. The current system has one smoothing weight for items with increasing BRFs and another value for all other items. The ARRSES computes a different value for each item based on the error between the item's BRF and the actual usage per unit of population the item experiences.

2. Approach. For repetitively demanded items, this study evaluated how accurately the BRFs produced by each system match the actual usage experienced by the items. While more than 970,000 items were in the data base for this study, only 30,000, about 3%, met the criteria for repetitively demanded items. To test a more representative sample of items, COSALs were built for three test ships. In building a COSAL, the BRF is used to forecast the demand for each candidate item. The demand is then used to determine the correct range and depth of items included in the COSAL.

BRFs produced by each of the three methods were used to build a series of test COSALs for each test ship. The supply effectiveness of each test COSAL was measured by comparing it against actual demands reported by the test ships. The COSAL effectiveness measures how well the forecasted demand matched the actual demands and this in turn reflects how accurately the BRFs predict the usage that occurred. Based on initial COSAL tests, the ARRSES option was rejected and the study was reduced to a comparison between the current and ratio methods of computing BRFs.

3. Results. The study showed that the current method is better in some areas and the ratio method is better in other areas. Specifically, the ratio method produces more accurate BRFs than the current method for repetitively demanded items. For this type of material, we found that 21% more ratio BRFs were within 50% of the actual usage than were current method BRFs. The ratio BRFs reduced the range of items on our test COSALs an average of 21% (1,873 items) and also reduced the cost an average of 19.5% or about $560,000 per COSAL. The ratio method reduced stock churn a small amount. The average number of range adds were reduced about 3.9% and less than 1.0% decreases were also

produced in the average number of range decreases and in the average number of items with quantity increases and decreases.

All COSALs based on current method BRFs had higher supply effectiveness than the equivalent ratio method COSALs. In terms of gross requisition effectiveness the current method COSALs were 2.6 percentage points higher than the ratio method COSALs. The average customer waiting time, which is a function of supply effectiveness, was 5% less for the current method COSAL than for the ratio COSAL.

4. Recommendations. As current COSAL effectiveness is below the goal set for it, we believe the ratio computation should be rejected because it reduces effectiveness still farther. We recommend that the current method of computing BRFs be continued.

I. INTRODUCTION

The Navy annually computes replacement rates for the parts used in its ships and shore installations. The rate indicates the number of times, per unit of installed population, that an item is expected to fail or be replaced by maintenance actions during the next year. This rate is called the item's Best Replacement Factor (BRF).

An item entering the Navy supply system is assigned a replacement rate called the Technical Replacement Factor (TRF). The TRF can be a technician's estimate, a value derived from a similar item's BRF or a value provided by the manufacturer. The TRF remains unchanged until the item has been in the system long enough for a normal pattern of demand to develop. A new replacement factor, called the BRF, is then computed. This new value is produced by adjusting the item's original TRF to reflect the item's actual usage. The BRF is retained for one year and then it is again updated to reflect the demands experienced during the latest year. This updating procedure is repeated annually for most items as long as they remain in the supply system.

Replacement rates are currently updated by computing a weighted average between the existing BRF and the average usage per unit of population experienced since the last update. The value assigned to the weighting factor (α) determines how each of the two components of the computation will affect the new BRF.

$$\text{NEW BRF} = (\alpha)\ \frac{\text{DEMAND SINCE LAST UPDATE}}{\text{AVERAGE POPULATION SINCE LAST UPDATE}} + (1-\alpha)(\text{OLD BRF})$$

A more detailed description of the current BRF computation is contained in APPENDIX B. As the value of the weighting factor approaches one, the impact of the current data increases and the influence of the old BRF declines. The effect is reversed as the weighting factor nears zero.

A review of annual updates shows that a majority of BRFs decrease in value every year but only a small percentage increase. TABLE I contains results of several yearly updates which illustrate this situation.

TABLE I

YEARLY BRF UPDATE STATISTICS

YEAR	PERCENT OF BRFs THAT DECREASED	PERCENT OF BRFs THAT WERE UNCHANGED	PERCENT OF BRFs THAT INCREASED
1979	52%	42%	6%
1980	55%	39%	6%
1981	54%	40%	6%
1982	58%	37%	5%
1983	53%	41%	6%

The tendency of the system to continuously reduce the BRFs of a majority of the items processed is not a problem in itself. It does, however, clearly show that BRF values in general are higher than actual usage indicates. (BRF values are reduced when the usage rate based on the latest actual usage and population data is smaller than the old BRF). TABLE I also shows that this situation has existed for an extended period of time. We believe the primary cause of the problem is the initial TRF value assigned to the BRF.

While TABLE I shows that BRFs tend to be too large and do not accurately represent actual usage for many items, a similar problem of inaccuracy exists with items having very small BRFs. Items exist in the system that have only very minimal usage, sometimes only one demand occurs during a period of five or even 10 years. A BRF for this type of item is very small and, based on its value, no demands would be expected in most years. If, then, a year passes without any usage reported for the item, the existing small BRF has correctly predicted that no demands are expected and there is no need to change it. The current system, however, will compute an average between the small current BRF and the zero usage during the latest year to produce a new still smaller BRF. If no usage occurs for several years, the annual recomputation will reduce the item BRF each year. However, when a demand does finally occur, the BRF may increase dramatically.

The current system thus produces BRFs for many items that are either too large or too small and do not accurately reflect actual usage. This study was initiated to determine if a more accurate method of computing BRFs could be found.

In 1982, a point paper was developed by NAVSSESDETMECH which proposed a change to the basic mathematics of the BRF computation. The paper recommended using the ratio of an item's total lifetime usage to the sum of its average annual populations as the BRF.

$$BRF = \frac{\text{TOTAL LIFE TIME DEMAND}}{\Sigma(\text{AVERAGE ANNUAL POPULATION})}$$

A detailed description of this procedure is provided in APPENDIX C. Each annual update would consist of adding the demand during the latest year to the previous total of lifetime demands and adding the item's average population during the year to the previous sum of average annual populations.

This procedure is based on reliability theory which shows that item replacement rates follow a "bathtub" shaped curve and remain more or less unchanged during the major portion of an item's useful life. Only when an item first enters the system and experiences a "break-in" period and at the conclusion of its useful life when a "wear-out" period occurs are significant changes found in an item's replacement rate. Except for these two short periods, the replacement rate should remain almost constant as long as no significant changes are made to the way the item is used.

If replacement rates do remain relatively constant over time, there should be little difference between a BRF that is a year old and the usage per unit of population shown by the latest year of data. Computing a weighted average of these two equal values is then a needlessly complicated way of computing BRFs. While a weighted average computation would respond quickly to upward or downward trends in the replacement rate, the assumption that the rate remains constant over time eliminates the need for this ability.

An additional method of computing BRFs is also examined in this study. The additional procedure is known as Adaptive-Response-Rate Single Exponential Smoothing (ARRSES). It is similar to the current method in that a smoothing weight (α_A) is used in computing an average between the last BRF and a replacement rate based on the latest data.

$$\text{NEW BRF}_A = (\alpha_A)\ \frac{\text{DEMAND SINCE LAST UPDATE}}{\text{AVERAGE POPULATION SINCE LAST UPDATE}} + (1-\alpha_A)(\text{OLD BRF}_A)$$

This procedure differs from the current method because it uses a different smoothing weight for each item while the current method uses only two smoothing weights, one for items with increased BRFs and a separate value for all other items. Using ARRSES, the annual update produces both a new BRF for each item, and also a new smoothing weight to be used in the items next annual update.

APPENDIX D contains a complete description of the ARRSES process.

II. APPROACH

In order to produce a comprehensive analysis of the accuracy achieved by the three methods of computing BRFs, the study looked at two types of data. The initial portion of the study focused on relatively fast moving items with repetitive demands. The second portion of the study, while still measuring BRF accuracy, also examined the impact BRFs have on Coordinated Shipboard Allowance List (COSAL) production. Data for the second part of the study included all types of items, not just the relatively small group with repetitive demands. Because the mix of items included in the last portion of the study are more representative of real life situations, findings based on that data have a greater impact on the study's recommendations than do the findings from the initial portion of the study.

III. ACCURACY EVALUATION - REPETITIVE DEMANDS

A. <u>REPETITIVE DEMANDS - DATA</u>. The data used in this study are the same data that were used to compute BRFs during the six years from 1976 to 1981. The data consist of population and usage data from three different sources; the Navy Maintenance and Material Management System (3M), the Mobile Logistic Support Force (MLSF) demand history, and the system transaction history data. Each item record in the file may contain all three types of data for each of the six years covered, it may be only partially completed with data voids in some years or the record may be entirely empty containing no data at all. A sample data record is shown in TABLE II.

TABLE II

SAMPLE BRF HISTORY RECORD

YEAR	BRF	3M DATA		MLSF DATA		SYSTEM DATA	
		USAGE	POPULATION	USAGE	POPULATION	USAGE	POPULATION
1976	0.0025	10	20	2	4	26	108
1977	0.3010	4	30	2	5	15	111
1978	0.2339	1	16	3	17	35	214
1979	0.1653	8	22	5	20	18	180
1980	0.3238	7	30	5	20	20	200
1981	0.2875	7	30	11	25	26	205

As TABLE II shows, the record also contains a BRF value for each year. In this example, the 1979 BRF had a value of 0.1653. This value was derived by computing the weighted average of the 1978 BRF and the 3M usage and population data reported during 1978. A weighting factor of 0.4 was used in this computation.

$$1979 \text{ BRF} = (0.4)\ \frac{1}{16} + (1.0 - 0.4)(.2339) = 0.1653$$

Throughout this study, 3M data were always preferred over the other two types of data and were always used when available. The MLSF data were used only when no 3M data were available and system data were only used when the other types of data were not available.

B. REPETITIVE DEMANDS - APPROACH. The initial portion of this study measured the accuracy of the BRFs computed for items with repetitive demands. As pointed out earlier, many of the history records available for this study contain data voids. To prevent this missing data from effecting the results, only records containing 3M population and usage data for each of the years from 1976 to 1981 were used. A total of 29,936 records contained the required data. This sample is about 3% of the total BRF history records.

In order to evaluate BRF accuracy, the purpose of the BRF must be clearly understood. An item's BRF is a forecast of how much usage the item will experience in the coming year. For example, a BRF of 0.1 forecasts that one tenth of the item's average population will be replaced during the year after the BRF is computed. This prediction of the items future usage is then used as the basis for making decisions on whether to include the item on a ship's COSAL or on a tender's load list and at what depth to carry it. This forecast is made by a mathematical calculation using the item's historical usage and population data. This study evaluated the accuracy with which the three different BRF procedures in question make this prediction of future usage.

Since the BRF is an attempt to forecast usage that will occur during the year after the computation is made, the obvious way to measure the success or failure of the prediction is to compare the usage occurring during that following year with the forecasted value. This was done by using the six years of data available for the study as both the raw data to compute BRFs and also as the measuring stick for determining accuracy. For example, data from 1978 were used to compute the 1979 BRF. The computed value was then compared to the item's 1979 usage and population data to determine the accuracy of the prediction. The 1979 data were then used to compute a 1980 BRF that was evaluated with 1980 data. Finally, the 1980 data were used to compute a 1981 BRF that was evaluated with 1981 data. This procedure was followed first with the ratio computation, which is the name used in the remainder of this paper for the mathematical calculations described in the NAVSSESDETMECH point paper, and was then repeated using the ARRSES computations. This procedure produced three observations of the ratio methods accuracy and also three observations of the ARRSES methods accuracy for each of the 29,936 records used for this portion of the study.

Since each record already contains BRFs computed using the current method, it was not necessary to compute new values for this accuracy evaluation. Instead, the BRF value in the record for year 1979, which had been computed using the item's 1978 data, was evaluated by comparing it to the item's 1979 3M usage and population data. Similarly, the 1980 and 1981 BRFs in each record were evaluated to obtain the three observations of the current method's accuracy needed for this study.

The item record shown in TABLE II can be used to demonstrate exactly how each accuracy measurement was made. When the ratio method was being evaluated, a ratio BRF for 1979 was first computed for the item.

$$1979 \text{ Ratio BRF} = \frac{\sum_{i=1976}^{i=1978} (\text{Usage}_i)}{\sum_{i=1976}^{i=1978} (\text{Population}_i)} = \frac{(10+4+1)}{(20+30+16)} = .2272$$

The computed ratio BRF forecasts that the replacement rate for this item in 1979 will be 0.2272 per unit of population. The actual 1979 rate is computed from the 1979 3M usage and population data.

$$\text{Actual 1979 Usage Rate} = \frac{\text{1979 3M USAGE}}{\text{1979 3M POPULATION}} = \frac{8}{22} = 0.3636$$

Based on 3M data, the actual usage rate in 1979 was 0.3636 per unit of population. The accuracy of the 1979 Ratio BRF is then determined by dividing the computed BRF by the actual usage rate.

$$1979 \text{ BRF}_R \text{ Accuracy} = \frac{\text{Computed BRF}}{\text{Actual Usage Rate}} = \frac{.2272}{.3636} = .6248 = 62.5\%$$

The evaluation shows that for this particular item, the 1979 Ratio BRF was equal to only 62.5% of the actual usage per unit of population.

While every evaluation of an individual BRF is in itself a measurement of the process used to compute it, it is only by collecting and organizing large numbers of observations in some appropriate manner that a truly reliable evaluation of the basic mathematical concepts is achieved. The process this study used to organize the data was to build a frequency distribution from the individual BRF accuracy measurements. The distribution consists of a series of cells, each of which is assigned a maximum and minimum value of accuracy so that all possible values are covered and each individual observation can be assigned to only one cell. TABLE III illustrates the frequency distribution used in this study.

TABLE III

ACCURACY EVALUATION FREQUENCY DISTRIBUTION FORMAT

CELL NUMBER	MAXIMUM VALUE ALLOWED IN CELL	MINIMUM VALUE ALLOWED IN CELL	RESTRICTED VALUES
	The BRF is no larger than:	The BRF is larger than:	This cell will not include any values:
1	105% of actual usage	95% of actual usage	-
2	110% of actual usage	90% of actual usage	included in cell 1
3	115% of actual usage	85% of actual usage	included in cells 1 & 2
4	120% of actual usage	80% of actual usage	included in cells 1 to 3
5	125% of actual usage	75% of actual usage	included in cells 1 to 4
6	130% of actual usage	70% of actual usage	included in cells 1 to 5
7	135% of actual usage	65% of actual usage	included in cells 1 to 6
8	140% of actual usage	60% of actual usage	included in cells 1 to 7
9	145% of actual usage	55% of actual usage	included in cells 1 to 8
10	150% of actual usage	50% of actual usage	included in cells 1 to 9
11	155% of actual usage	45% of actual usage	included in cells 1 to 10
12	160% of actual usage	40% of actual usage	included in cells 1 to 11
13	165% of actual usage	35% of actual usage	included in cells 1 to 12
14	170% of actual usage	30% of actual usage	included in cells 1 to 13
15	175% of actual usage	25% of actual usage	included in cells 1 to 14
16	180% of actual usage	20% of actual usage	included in cells 1 to 15
17	185% of actual usage	15% of actual usage	included in cells 1 to 16
18	190% of actual usage	10% of actual usage	included in cells 1 to 17
19	195% of actual usage	5% of actual usage	included in cells 1 to 18
20	200% of actual usage	0% of actual usage	included in cells 1 to 19
21	250% of actual usage	200% of actual usage	included in cells 1 to 20
22	300% of actual usage	250% of actual usage	included in cells 1 to 21
23	350% of actual usage	300% of actual usage	included in cells 1 to 22
24	400% of actual usage	350% of actual usage	included in cells 1 to 23
25	500% of actual usage	400% of actual usage	included in cells 1 to 24
26	NO MAXIMUM	500% of actual usage	included in cells 1 to 25

This frequency distribution will count the number of observations that fall within the maximum and minimum cell limits and also are not excluded by the restrictions listed under the "RESTRICTED VALUES" column.

This frequency distribution can be thought of as a target or bull's-eye, such as those used in archery contests. Each of the concentric circles in the archery target represents a different degree of accuracy. In the same way each of the 26 cells in the frequency distribution represents different levels of accuracy with cell number 1, which represents the highest degree of accuracy, being the equivalent of the bull's-eye in the archery target.

To carry the analogy one step further, the best or most accurate archer is the one who can shoot the most arrows into or closest to the bull's-eye. Similarly, in our study, the most accurate method of computing BRFs for items with repetitive demands is the procedure which has the largest number of accuracy observations in or nearest to the cell number one bull's-eye.

C. REPETITIVE DEMANDS - FINDINGS. Using the three observations of accuracy from each history record and the frequency distribution format shown in TABLE III, separate distributions were formed for each of the three mathematical procedures being evaluated. These distributions are shown in TABLE IV. Columns A, D, and E are data from the accuracy observations of the current procedure for computing BRFs. Column A shows the number of observations that fall into each of the 26 levels of accuracy represented by the cells in the distribution. Column D provides cumulative totals of the data from Column A. Column E shows the percentage of all observations of current method accuracy that are represented by the cumulative values in Column D. Columns B, F. and G show the same data for the ratio method of computing BRFs. Columns C, H and I contain data about ARRSES accuracy.

TABLE IV

OBSERVATIONS OF BRF ACCURACY

Frequency Distributions				Cumulative Totals					
A CURRENT METHOD	B RATIO METHOD	C ARRSES METHOD	CELL NR	D CURRENT METHOD	E PERCENT	F RATIO METHOD	G PERCENT	H ARRSES METHOD	I PERCENT
4693	6885	5090	01	4693	5%	6885	7%	5090	5%
4342	6381	4564	02	9035	10%	13266	14%	9654	10%
4135	6068	4569	03	13170	14%	19334	21%	14223	15%
4011	6221	4567	04	17181	19%	25555	28%	18790	21%
3795	5852	4248	05	20976	23%	31407	35%	23038	25%
3817	5719	4344	06	24793	27%	37126	41%	27382	30%
3530	5376	4461	07	28323	31%	42502	47%	31843	35%
3248	5024	[illegible]	08	31571	35%	47526	53%	36212	40%
3099	[illegible]	[illegible]	09	34670	38%	51993	58%	40415	45%
2932	4032	4362	10	37602	41%	56025	62%	44777	50%
2585	3289	3882	11	40187	44%	59314	66%	48659	54%
2601	2800	3885	12	42788	47%	62114	69%	52544	58%
2201	2183	3472	13	44989	50%	64297	71%	56016	62%
1989	1758	3378	14	46978	52%	66055	73%	59394	66%
1826	1577	2888	15	48804	54%	67632	75%	62282	69%
1629	1368	2489	16	50433	56%	69000	77%	64771	72%
1448	1189	2191	17	51881	57%	70189	78%	66962	74%
1463	1173	1767	18	53344	59%	71362	79%	68729	76%
1347	1064	1361	19	54691	60%	72426	80%	70090	78%
1617	1361	1263	20	56308	62%	73787	82%	71353	79%
7045	4565	4794	21	63353	70%	78352	87%	76147	84%
4784	2841	3062	22	68137	75%	81193	90%	79209	88%
3364	1762	1979	23	71501	79%	82955	92%	81188	90%
2520	1302	1479	24	74021	82%	84257	94%	82667	92%
3537	1623	1928	25	77558	86%	85880	95%	84595	94%
12250	3928	5213	26	89808	100%	89808	100%	89808	100%

Earlier discussions pointed out that the procedure which has the most observations in or near cell 1 of the distribution is the most accurate estimator of actual usage. A comparison among the cumulative totals in

TABLE IV shows that the ratio computation has the highest number of observations in cell 1 and also at every other level in the distribution. Based on this evidence, the ratio computation is the most accurate method of computing BRFs for repetitively demanded items.

Cells 21 through 26 of the distribution count the items for which the computed BRFs are more than double the actual usage per unit of population. The current method of computing BRFs produced 33,500 forecasts, 37.3% of the total BRFs computed by the current method, which are more than twice the size of the actual usage per unit of population. Only 16,021 (17.8%) of the ratio BRFs and 18,455 (20.5%) of the ARRSES BRFs were more than two times the actual usage for the item. We pointed out earlier in this paper that the high initial TRFs assigned to items cause many BRFs computed by the current system to be too large. The data in cells 21 through 26 demonstrate that a significant portion of current method BRFs are excessively large and that less than half as many ratio BRFs are this inaccurate. The fact that the ratio BRF does not use initial TRF values in computing future usage is a principal reason for the difference.

The evaluations of repetitively demanded items clearly showed that the ratio method is a better procedure for computing BRFs than the current method. These results, however, are not comprehensive. First, they are based on a small sample of items (3%) and secondly, the items are a "special" type in that they are repetitively demanded. The general population of items do not fit this description. For example, there are almost three times as many items (87,331 records or 8.9%) with only one year of 3M usage as there are items with six years of 3M usage.

In the second part of this study, the accuracy tests are based on items more representative of the general population. The question asked is whether the ratio method can perform as well in a real life environment as it did in the first part of the study.

IV. ACCURACY EVALUATION - COSAL IMPACT

The remainder of the study examines the ways that the three different methods of computing BRFs affect COSALs. A COSAL is the range and depth of items each ship carries as replacements for failed parts and to support normal maintenance requirements. In order to compile this allowance list, the expected demand is computed for each candidate item by multiplying the items BRF times its population on the ship. This expected demand is then used to select the COSAL range from the available candidates and to determine the appropriate depth of the selected items. Because each item's BRF plays such an important part in building COSALs, changing the method of computing BRFs might produce significant changes in future COSALs. This study quantifies any such COSAL changes that may occur if a new method of computing BRFs is implemented.

A. COSAL IMPACT - DATA. The data for this part of the study were generated by building a series of COSALs for several ships and then comparing the results. The ships selected for this study were the USS COOK (FF 1083), the USS LOS ANGELES (SSN 688) and the USS FRESNO (LST 1182). The candidate files which were used to build the latest COSAL for each of the three test ships were obtained to build the test COSALs for this portion of the study.

B. COSAL IMPACT - APPROACH. Each item of the three candidate files was matched against the BRF history file used in the first part of the study. Each history record contained BRFs for 1978, 1979, 1980 and 1981. These BRFs were computed using current procedures. The 1978 current method BRFs were taken from the history records and entered in the appropriate positions in the COSAL candidate records. A COSAL was then built for each of the three test ships using these 1978 current method BRFs. The procedure was repeated using the 1979, 1980 and 1981 current method BRFs to produce a total of four test COSALs for each test ship.

The population and usage data from each of the history records were then used to build BRFs with the ratio computation method. Data from 1978 were used to build a 1979 ratio BRF, data from 1979 produced 1980 ratio BRFs, and 1980 data produced 1981 ratio BRFs. Because the history records used in this part of the study could not be limited to items with 3M data, as they had been for the accuracy evaluations, some ratio BRFs were built with 3M data, others with MLSF data and the remainder with system data. Each of the 1979, 1980, and 1981 ratio method BRFs computed for each candidate item were then used to build another COSAL for each ship.

Finally, the same usage and population data used to build ratio method BRFs were used again to build BRFs with the ARRSES computation method. These ARRSES BRFs were then used to build three more COSALs for each test ship. In short, 10 COSALs were built for each test ship, four using current method BRFs, three using ratio BRFs and three using ARRSES method BRFs.

Initial tests of the 10 COSALs produced some results which confirmed findings from the first part of the study. Just as the ratio method BRFs were more accurate than ARRSES BRFs in the first part of the study, preliminary COSALs based on ratio BRFs have higher supply effectiveness than ARRSES COSALs in the second part of the study. Based on these findings, the ARRSES method of computing BRFs was rejected as a possible replacement for current procedures. The remainder of the study consists of comparisons between COSALs based on current method BRFs and COSALs based on ratio BRFs.

We measured the impact on the COSAL of the alternative BRF computations in several ways. We examined the impact on the COSAL's range and dollar value; stock churn (i.e., number of items added or deleted from one COSAL recomputation to another), range, requisition, units effectiveness, and Average Customer Waiting Time (ACWT) (i.e., the average time the customer has to wait for a part).

C. COSAL IMPACT - FINDINGS.

1. COSAL Range and Dollar Value. Four COSALs based on current BRFs and three based on ratio BRFs were built for each of the test ships. Range and extended dollar value statistics for these COSALs are shown in TABLE V.

TABLE V

COSAL RANGE AND DOLLAR VALUE

	FF 1083		SSN 688		LST 1182	
BRF Used To Compute COSAL	SRI Range	SRI $ Value	SRI Range	SRI $ Value	SRI Range	SRI $ Value
1978 Current	13340	$3.58MIL	9587	$4.77MIL	7519	$1.42MIL
1979 Current	13878	$3.32MIL	9806	$4.86MIL	7790	$1.49MIL
1980 Current	13977	$3.19MIL	10003	$4.75MIL	7976	$1.44MIL
1981 Current	13770	$3.14MIL	9926	$5.36MIL	7802	$1.44MIL
1979 Ratio	8850	$2.71MIL	7396	$4.17MIL	5583	$1.22MIL
1980 Ratio	8795	$2.58MIL	6990	$3.94MIL	5552	$1.23MIL
1981 Ratio	8631	$1.94MIL	6692	$3.80MIL	5374	$1.16MIL

TABLE V shows that COSALs based on ratio method BRFs contain a smaller range of items and cost less than COSALs built with current method BRFs. The difference in range is significant. The current method BRF COSALs for the FF 1083 contain an average of 4,983 more items (57%) than the ratio COSALs for the same ship. For the other two ships, the average differences are smaller, 2804 items (40%) for the SSN and 2269 items (41%) for the LST, but they are still significant. The dollar value differences range from a maximum of $1,560,000 for the difference between the SSN's two 1981 COSALs to a minimum of $210,000 for the difference between the LST's two 1980 COSALs.

C. COSAL - Stock Churn. A major Fleet concern when a new COSAL replaces a current COSAL is the amount of "stock churn" that always occurs. Stock churn refers to the items on a ship's current COSAL which are not included in its new COSAL or vice versa. Normally a ship receives a new COSAL only after an overhaul, about once every five years. For the purposes of our study, we have assumed that new COSALs are produced every year. Since we are only interested in the relative difference between the stock churn from ratio based COSALs and that from current method COSALs this procedure produces acceptable results.

Because the COSAL is designed to include insurance items that have only a small probability of being demanded, many COSAL items are not used. However, when nonmoving items are off-loaded during a COSAL change only to be replaced by new items which also do not move, questions arise about the usefulness of the new COSAL, about the procedures used to build the COSAL and about the data used in the computation.

In light of the concern about stock churn, this study measured the changes that occured when one COSAL is replaced by another. These data were collected by comparing each of the test COSALs against the test COSAL for the following year. Using this procedure, the study collected churn data on both the current COSALs and the ratio BRF COSALs built for each of the test ships. The churn statistics for the FF, the SSN and the LST are shown in TABLES VI, VII, and VIII, respectively. The tables contain counts on the number of items that are added and deleted when COSALs change. They contain similar counts of the number of items that experience depth increases or decreases. The tables present both the actual quantity differences and also the equivalent values computed as a percentage of the previous COSAL range.

We note that the COSAL ranges shown in TABLES VI, VII, and VIII are smaller than the ranges shown in TABLE V for the same COSAL. The differences are caused by a few items on the COSAL which have duplicate records. The data shown in TABLE V count the duplicate records as separate items. This produces a larger range count than in TABLES VI, VII, and VIII where the duplicate records are not counted. None of the items with duplicate records are adds, deletes, increases or decreases so they have not effected these counts in TABLES VI, VII, or VIII.

TABLE VI

STOCK CHURN - FF COSALS

CURRENT METHOD BRFS

		RANGE	$ VALUE (MILLIONS)	RANGE		DEPTH	
				ADDS	DELETES	INCREASE	DECREASE
1978	C	12,768	$1.323				
	D	524	2.250	N/A	N/A	N/A	N/A
	T	13,292	$3.573				
1979	C	13,269	$1.323	1,364	863	385	394
	D	561	1.995	57	20	1	1
	T	13,830	$3.318	1,421	883	386	395
% CHNG				10.6%	6.6%	2.9%	3.0%
1980	C	13,349	$1.147	922	842	413	424
	D	580	2.037	34	15	2	2
	T	13,929	$3.184	956	857	415	426
% CHNG				6.9%	6.2%	3.0%	3.1%
1981	C	13,138	$1.130	749	960	283	642
	D	584	2.004	43	39	2	2
	T	13,722	$3.134	792	999	285	644
% CHNG				5.7%	7.2%	2.0%	4.6%

RATIO METHOD BRFS

		RANGE	$ VALUE (MILLIONS)	RANGE		DEPTH	
				ADDS	DELETES	INCREASE	DECREASE
1979	C	8,396	$0.834				
	D	406	1.874	N/A	N/A	N/A	N/A
	T	8,802	$2.708				
1980	C	8,363	$0.849	442	476	239	315
	D	384	1.727	19	40	2	1
	T	8,747	$2.576	461	516	241	316
% CHNG				5.2%	5.9%	2.7%	3.6%
1981	C	8,240	$0.824	296	418	106	340
	D	343	1.109	17	58	0	2
	T	8,583	$1.933	313	476	106	342
% CHNG				3.6%	5.4%	1.2%	3.9%

C = Consumables D = DLR T = Total

% change is a measure of adds, deletes, increases, decreases as a percentage of the previous years total range.

TABLE VII

STOCK CHURN - SSN COSALS

CURRENT METHOD BRFS

	RANGE	$ VALUE (MILLIONS)	RANGE		DEPTH	
			ADDS	DELETES	INCREASE	DECREASE
1978 C	8,975	$1.769				
D	570	2.985	N/A	N/A	N/A	N/A
T	9,545	$4.754				
1979 C	9,164	$1.596	795	614	308	355
D	600	3.264	75	45	6	1
T	9,764	$4.860	870	659	314	356
% CHNG			9.1%	6.9%	3.3%	3.7%
1980 C	9,373	$1.500	849	639	226	361
D	588	3.249	54	66	4	4
T	9,961	$4.749	903	705	230	365
% CHNG			9.3%	7.2%	2.4%	3.7%
1981 C	9,226	$1.389	585	731	207	439
D	658	3.966	122	52	12	4
T	9,884	$5.355	707	783	219	443
% CHNG			7.1%	7.9%	2.2%	4.4%

RATIO METHOD BRFS

	RANGE	$ VALUE (MILLIONS)	RANGE		DEPTH	
			ADDS	DELETES	INCREASE	DECREASE
1979 C	7,017	$1.655				
D	337	2.513	N/A	N/A	N/A	N/A
T	7,354	$4.168				
1980 C	6,577	$1.099	299	738	140	273
D	371	2.836	60	26	9	2
T	6,948	$3.935	359	764	149	275
% CHNG			4.9%	10.4%	2.0%	3.7%
1981 C	6,278	$1.005	221	515	81	244
D	372	2.795	26	25	2	5
T	6,650	$3.800	247	540	83	249
% CHNG			3.6%	7.8%	1.2%	3.6%

C = Consumables D = DLR T = Total

% change is a measure of adds, deletes, increases, decreases as a percentage of the previous years total range.

TABLE VIII

STOCK CHURN - LST COSALS

CURRENT METHOD BRFS

	RANGE	$ VALUE (MILLIONS)	RANGE ADDS	RANGE DELETES	DEPTH INCREASE	DEPTH DECREASE
1978 C	7,218	$0.656				
D	245	0.765	N/A	N/A	N/A	N/A
T	7,463	$1.421				
1979 C	7,485	$0.712	809	542	216	301
D	249	0.773	10	6	2	4
T	7,734	$1.485	819	548	218	305
% CHNG			11.0%	7.3%	2.9%	4.1%
80 C	7,660	$0.628	656	481	204	313
D	260	0.812	19	8	1	4
T	7,920	$1.440	675	489	205	317
% CHNG			8.7%	6.3%	2.7%	4.1%
1981 C	7,483	$0.627	429	606	155	378
D	263	0.809	11	8	3	3
T	7,746	$1.436	440	614	158	381
% CHNG			5.6%	7.8%	2.0%	4.8%

RATIO METHOD BRFS

	RANGE	$ VALUE (MILLIONS)	RANGE ADDS	RANGE DELETES	DEPTH INCREASE	DEPTH DECREASE
1979 C	5,303	$0.511				
D	224	0.704	N/A	N/A	N/A	N/A
T	5,527	$1.215				
1980 C	5,267	$0.532	245	281	121	191
D	229	0.696	10	5	1	0
T	5,496	$1.228	255	286	122	191
% CHNG			4.6%	5.2%	2.2%	3.5%
1981 C	5,093	$0.484	167	341	51	219
D	225	0.678	3	7	1	1
T	5,318	$1.162	170	348	52	220
% CHNG			3.1%	6.3%	1.0%	4.0%

C = Consumables D = DLR T = Total

% change is a measure of adds, deletes, increases, decreases as a percentage of the previous years total range.

The data in these tables indicate that the changes (churn) between current BRF COSALs are usually larger than the changes (churn) between ratio BRF COSALs. The single exception noted in the study occurred in the 1980 COSAL for the SSN (see TABLE VII). Here the number of deletes between consecutive ratio based COSALs exceeded the number of deletes for current COSALs for the same years.

3. COSAL Effectiveness. A COSAL is the list of spare parts that a ship carries as replacements for defective parts and to meet normal maintenance requirements. To measure how well each of the test COSALs satisfies this goal, each was compared to actual 3M usage reported by the respective test ships. The 3M data used to measure COSAL effectiveness spanned a later time period than the 3M data from the BRF history files that were used to compute the BRFs. Data for the effectiveness evaluations covered a three year period from January 1982 to December 1984.

The three years of 3M data represents 12 consecutive quarters of demand while a COSAL is designed to provide support for 90 days or one quarter. In the effectiveness measurement program used in this study, each of the 12 quarters of 3M demand is matched against the same COSAL, one quarter at a time. It is assumed that the complete COSAL range and depth are available at the beginning of each quarter, but no resupply of stock is allowed during a quarter. A separate effectiveness is computed for each quarter. After all data have been processed, the total effectiveness for the three years of data is computed. TABLE IX contains the results of the effectiveness evaluations of the 1981 test COSALs built for the three test ships. The statistics in the table show the total effectiveness for the three year demand period. The range effectiveness indicates the percentage of NIINs demanded that are on the COSAL. Similarly, the units effectiveness measures the percentage of units demanded that the COSAL can supply. Requisition effectiveness is the percentage of requisitions that the COSAL can satisfy. In measuring requisition effectiveness a partially filled requisition is counted as filled. For example, if five are ordered, but only one is issued, the requisition is still counted as being satisfied. The gross effectiveness shown in the table is the percentage of all the demands received that the COSAL could supply. Model effectiveness shows the percentage of demands for candidate items that were satisfied. Net effectiveness measures the percentage of demands for items on the COSAL that could be filled.

TABLE IX

COSAL SUPPLY EFFECTIVENESS
Compare Current and Ratio Methods

	1981 FF COSALs		1981 SSN COSALs		1981 LST COSALs	
BRF Used to Build COSAL	Current Method	Ratio Method	Current Method	Ratio Method	Current Method	Ratio Method
Range (SRI Items)	13,770	8,631	9,926	6,692	7,802	5,374
$ Value (Millions)	$3.14	$1.94	$5.36	$3.80	$1.44	$1.16
Range EFF						
Gross	0.462	0.413	0.471	0.431	0.432	0.389
Model	0.758	0.677	0.822	0.754	0.799	0.720
Units EFF						
Gross	0.270	0.233	0.213	0.194	0.181	0.158
Model	0.465	0.401	0.519	0.473	0.385	0.335
Net	0.487	0.428	0.546	0.507	0.435	0.359
Requisition EFF						
Gross	0.467	0.427	0.506	0.468	0.419	0.386
Model	0.727	0.664	0.777	0.718	0.710	0.653
Net	0.875	0.859	0.864	0.849	0.822	0.808

A review of TABLE IX shows that in every comparison, COSALs based on current method BRFs outperform, or have a higher effectiveness, then the COSALs based on ratio method BRFs. Because these results seemed to contradict the earlier accuracy evaluations, additional analysis of the data and the procedures used in the COSAL comparisons was made.

As described earlier, ratio BRFs were computed especially for the study, but the current BRFs were taken from the history file. It was assumed that the BRFs in each record were derived from and based on the usage and population data in the record. This is not true for all items. The current system of computing BRFs allows the BRF to be changed manually during reviews. When these changes are made, the BRFs in the record no longer reflect the actual usage and population data in the record.

The volume of manual changes made during the review process cannot be determined. Some changes were never documented and for others, the documentation is incomplete or missing. As a result, it is impossible to accurately identify all the records in the file that were changed in some way.

For the same reasons, all the items used in the study that contain manually changed BRFs cannot be identified. Several attempts were made to find them and in some cases the attempts were successful. For example, some ordnance-related items are assigned BRF floors. This allows the BRF to increase if the demand warrants it, but prevents any decreases. Another group of items had migrated from one cognizance symbol to another. As part of this process, the item's BRFs were frozen. Originally, when these items were identified, attempts were made to adjust the ratio BRFs in the same way that the current procedure BRFs had been revised. When it became apparent that finding and correcting all the data problems was an impossible task, this attempt was abandoned.

Instead, it was apparent that to eliminate all the effects of the data changes, new current method BRFs had to be computed for every item. By using the same usage and population data used to compute the ratio BRFs, the danger of the data biasing the effectiveness comparisons was virtually eliminated. Even if some invalid data were included in the computations it would effect both the ratio and current BRFs equally. This procedure was followed. New "pure" BRFs were computed for every item using the mathematical procedures described in APPENDIX B. The new rates are identified as "pure" BRFs because they have been computed using only the data in the item record and the procedures described in APPENDIX B. No manual changes, ordnance freezes or other variations to values computed by following the current procedure were allowed. The pure BRFs were then used to produce a series of test COSALs. The effectiveness of the new COSALs was evaluated using the same 3M data used earlier to measure effectiveness.

In TABLE X, the effectiveness of the pure BRF COSALs is compared to that of the ratio COSALs and the current method COSALs based on BRFs taken directly from the history records.

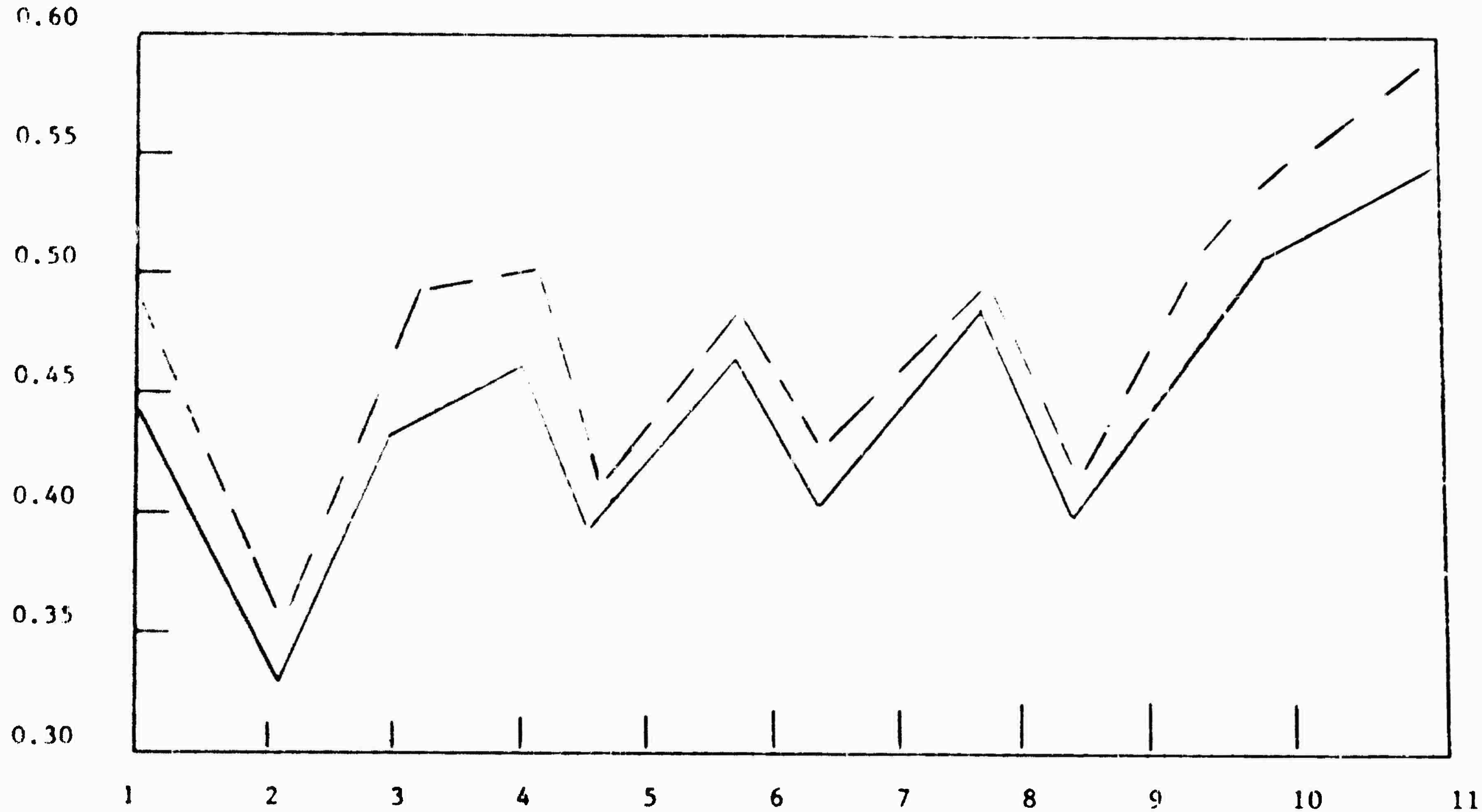
TABLE X

1981 COSAL SUPPLY EFFECTIVENESS
Compare Current, Pure and Ratio Methods

	FF COSALs			SSN COSALs			LST COSALs		
BRF Used to Build COSAL	Current Method	Pure Data	Ratio Method	Current Method	Pure Data	Ratio Method	Current Method	Pure Data	Ratio Method
Range (SRI Items)	13,770	11,922	8,631	9,926	7,892	6,692	7,802	6,502	5,374
$ Value (Millions)	$3.14	$2.78	$1.94	$5.36	$4.35	$3.80	$1.44	$1.45	$1.16
Range EFF									
Gross	.462	.449	.413	.471	.454	.431	.432	.420	.389
Model	.758	.737	.677	.822	.793	.754	.799	.777	.720
Units EFF									
Gross	.270	.266	.233	.213	.204	.194	.181	.173	.158
Model	.465	.458	.401	.519	.498	.473	.385	.366	.355
Net	.487	.480	.428	.546	.523	.507	.435	.385	.359
Requisition EFF									
Gross	.467	.457	.427	.506	.491	.468	.419	.412	.386
Model	.727	.714	.664	.777	.754	.718	.710	.698	.653
Net	.875	.873	.859	.864	.858	.849	.822	.818	.808

The table shows that the pure BRF COSALs are less effective than the current method COSALs built earlier, but they still outperform the COSALs built with ratio BRFs. Using gross requisition effectiveness as an example, we see that using pure data reduced the effectiveness of the current method COSALs only 1.0 percentage points for the FF (46.7% to 45.7%), 1.5 percentage points for the SSN (50.6% to 49.1%) and 0.7 percentage points for the LST (41.9% to 41.2%). The pure data COSAL still had a higher gross requisition effectiveness than the corresponding ratio COSAL. The differences in effectiveness is 3.0 percentage points for the FF (45.7% to 42.7%), 2.3 percentage points for the SSN (49.1% to 46.8%) and 2.6 percentage points for the LST (41.2% to 38.6%). Similar results are shown for all the other effectiveness measures displayed in the table.

All effectiveness data shown in TABLES IX and X represent the total values for the three years of demand data used in the study. As explained earlier, the effectiveness program also computes the effectiveness of each individual quarter during the three years. FIGURE 1 contains a graph in which 11 quarters of effectiveness for the 1979 ratio BRF COSAL built for the FF are compared to 11 quarters of effectiveness achieved by the 1979 pure BRF COSAL built for the same ship. The twelfth quarter of effectiveness was omitted because the demand data for that quarter is suspect. While more than 1000 requisitions were reported in two quarters and at least 163 requisitions were reported in every other quarter, only 11 requisitions were reported in the twelfth quarter.



QUARTER
QUARTERLY GROSS REQUISITION EFFECTIVENESS

FIGURE 1

——— 1979 FF Ratio COSAL
------- 1979 FF Pure Current COSAL

As the graph clearly shows, the effectiveness of each individual quarter follows the same pattern found when the three year totals were compared. The current procedure using pure data produces a BRF that builds a more effective COSAL then the ratio BRF.

4. COSAL Average Customer Waiting Time. A recent operations analysis study involving the readiness of the Navy supply system included a mathematical analysis of the relationship between various levels of the supply system and the average waiting time experienced by a customer placing a requirement on the system. This analysis produced a program which converts the supply effectiveness achieved at the retail, wholesale or another level of the system into an expected ACWT. In TABLEs IX and X differences in COSAL effectiveness are shown in terms of percentage points. TABLE XI shows the results when COSAL effectiveness is converted into the expected number of hours a customer will wait, on the average, to have his requirements filled. The effectiveness data used are the total three year effectiveness for the FF COSALs shown before in TABLE X.

TABLE XI

AVERAGE CUSTOMER WAITING TIME
1981 FF COSAL

	Gross Requisition Effectiveness	Average Customer Waiting Time
COSAL Effectiveness Goal	65.0%	114.32 Hrs
COSAL Built With Pure Current Method BRFs	45.7%	176.25 Hrs
COSAL Built With Ratio BRFs	42.7%	185.88 Hrs

Although neither the current method BRF COSAL nor the ratio method COSAL meets the ACWT goal of 114 hours, the current method reduces ACWT by 9.63 hours over the ratio method.

V. SUMMARY AND CONCLUSIONS

This study evaluated alternative methods of computing BRFs. The evaluation consisted of measuring, in various ways, the accuracy of the BRFs each method produces. This was done both directly, by comparing BRF values with actual usage, and indirectly, by testing COSALs built from the BRFs. The COSAL evaluations included comparisons of range, cost, stock churn and supply effectiveness.

Tests of repetitively demanded items, which had usage in all six years covered by the data, clearly demonstrated that the ratio method was more accurate for these items. As an example, 62% of all ratio BRFs were within 50% of the usage per unit of population that actually occurred. Only 41% of the current method BRFs were able to achieve this degree of accuracy.

The accuracy tests in the remainder of the study involved various aspects of COSAL development. The data in these COSAL tests were more representative of the mix of items in the supply system than the data in the initial tests. The results of the COSAL tests were split. The ratio BRFs reduced range, cost and stock churn. As TABLE XII shows, the ratio BRFs reduced the range of 1981 COSALs an average of 21.3% and reduced cost an average of 19.5%.

TABLE XII

COSAL COMPARISON SUMMARY

	COSAL RANGE			COSAL COST (MILLIONS)		
	FF	SSN	LST	FF	SSN	LST
1981 Pure Data COSAL	11,922	7,892	6,502	$2.78	$4.35	$1.45
1981 Ratio COSAL	8,631	6,692	5,374	1.94	3.80	1.16
Actual Change	3,291	1,200	1,128	0.84	0.55	0.29
Percent Change	27.6%	15.2%	17.3%	30.2%	12.6%	20 0%
Average Percent Change for all three ships	21.3%			19.5%		

The reduction in COSAL range is the principal reason for the reduction in cost found in the ratio BRF COSALs.

Comparisons of stock churn showed that on the average current method COSAL 8.2% of the items are adds and 7.0% of the previous COSAL items are deleted. In the average ratio method COSAL only 4.3% of the items are adds and 6.8% of the previous COSAL items are deleted. There is less than 1.0% difference between the two types of COSALs in the number of items with depth increases or decreases. When COSAL supply effectiveness is measured, however, COSALs based on current method BRFs had the better supply effectiveness. In terms of gross requisition effectiveness, the current method COSALs have an average of 2.6 percentage points higher supply effectiveness. In all other effectiveness measures, current method COSALs also have higher effectiveness with the maximum average improvement of 5.2 percentage points found in model range effectiveness and the minimum average improvement of 1.1 percentage points occurring when net requisition effectiveness is measured. Additional analysis also showed that the current method COSALs had higher effectiveness across categories of items such as consumable, depot level repairable, and Item Mission Essentiality Codes (IMECs). The current method COSALs also have a 5% shorter average customer waiting time.

The study findings can basically be reduced to the facts that the ratio method produces the most accurate BRFs for repetitively demanded items, while current method BRFs produce COSALs that have higher supply effectiveness but are also more expensive. While ratio BRFs are more accurate for items with repetitive demands, these items represent only a small part of the items in the supply system. For a more representative mix of items, the current method produces BRFs that more accurately reflect COSAL requirements and, therefore, produce COSALs with higher supply effectiveness. This increased effectiveness is achieved at a cost, however, because the current method COSALs in the study were 19.5% (approximately $560,000) more expensive on the average than the ratio BRF COSALs. Stock churn findings are less significant because the differences between the two types of COSALs are very small and better methods probably exist for reducing stock churn.

VI. RECOMMENDATIONS

Because current COSAL supply effectiveness is already below established goals and because the ratio method will reduce COSAL effectiveness still farther, we recommend retaining the current method of computing BRFs.

APPENDIX A: REFERENCES

1. Makridakis, S., and S. Wheelwright, 1978. Forecasting Methods and Applications. New York: John Wiley and Sons.

APPENDIX B: THE CURRENT WEIGHTED AVERAGE COMPUTATION OF BEST REPLACEMENT FACTORS

Best Replacement Factors (BRFs) are currently produced by computing a weighted average between the item's current BRF and the replacement rate computed from the latest year of data.

$$\text{NEW BRF} = (\alpha)\left(\frac{\text{LATEST YEAR OF USAGE}}{\text{AVERAGE POPULATION IN LATEST YEAR}}\right) + (1-\alpha)(\text{CURRENT BRF})$$

The smoothing weight, α, in this equation is assigned two different values. If the item's BRF is increasing, a weighting factor of 0.8 is used. If the BRF is decreasing, the value is 0.4. These values can be changed as policies concerning the BRF are revised. Other values have been used at various times in the past.

The average population is obtained by computing the simple average of the item's population at the beginning of the year and its population at the end of the year.

$$\text{AVG POPULATION} = \frac{(\text{POPULATION AT BEGINNING OF YEAR}) + (\text{POPULATION AT END OF YEAR})}{2}$$

Three different sources provide the data used to compute BRFs; the Navy Maintenance and Material Management System (3M), the Mobile Logistics Support Force (MLSF) demand history, and system transaction history data. Data from the 3M system are believed to be more accurate, complete and timely than that from the other sources so they are always used when available. MLSF data are the preferred second choice and are used when there are no 3M data. BRFs are computed from system transaction history data only if other data are not available.

A series of nonmathematical routines are also part of the current computation program. These routines are applied both before and after the BRF is computed. Before the computation, checks insure that an item has been in the supply system long enough, that it has sufficient population and that enough valid 3M data are available for a BRF computation. There are also checks for codes which allow the BRF of some ordnance related items to increase but not to decrease.

After the BRF has been computed there are checks which limit the size of BRF increases and which select items for a manual review. The values assigned o these filters and constraints can be adjusted as needed to fit the latest policy. None of these nonmathematical routines are directly effected by the current study.

APPENDIX C: RATIO METHOD OF COMPUTING BRFs

The ratio method of computing BRFs is composed of a set of rules and several simple mathematical computations.

Rule 1. No BRF Computations During the Demand Development Period. During the first two years that an item is in the supply system, the demand development period, the Technical Replacement Factor (TRF) assigned to the item is the BRF. This rule also applies to the current BRF.

Rule 2. Compute a New BRF After Two Demands Occur. At the end of the demand development period, begin counting demands for the item. When the second demand for the item occurs, compute a new BRF using the ratio method of computation.

$$\text{NEW BRF} = \frac{\text{TOTAL LIFETIME DEMAND FOR THE ITEM}}{\Sigma(\text{ANNUAL AVERAGE POPULATIONS})}$$

Demands occurring during the demand development period are not included in the count to determine when a new BRF should be computed. However, demands occurring during those first two years are included in the total lifetime demand which forms the numerator of the BRF computation.

Each year the item's average population is determined by computing the simple average of the population at the beginning and at the end of the year.

$$\text{AVERAGE POPULATION} = \frac{(\text{POPULATION AT START OF YEAR}) + (\text{POPULATION AT END OF YEAR})}{2}$$

All of the item's average yearly populations are added together to form the denominator of the BRF computation.

Rule 3. If Beyond the Demand Development Period Without Two Demands, Check the TRF. If two demands have not occurred so that a BRF can be computed, the item's TRF is checked. Compute the "expected demand" for the item based on its TRF.

$$\text{"EXPECTED DEMAND"} = (\text{TRF}) \times (\Sigma\text{ANNUAL AVERAGE POPULATION})$$

If the value of the "expected demand" is less than 2.0, the TRF is retained with no changes. If the "expected value" is equal to or greater than 2.0, new replacement factor is computed for the item.

$$\text{NEW REPLACEMENT FACTOR} = \frac{1.0}{(\Sigma\text{ANNUAL AVERAGE POPULATIONS})}$$

This "new replacement factor" will be used until two demands occur and a BRF is computed or until the value of the "expected demand" based on the new replacement factor equals or exceeds 2.0.

APPENDIX D: ADAPTIVE-RESPONSE-RATE SINGLE EXPONENTIAL SMOOTHING (ARRSES)

The ARRSES method of forecasting used in this study produces a BRF by computing a smoothed average between the replacement rate derived from the latest year of data and the replacement rate computed for the item at the last BRF update.

$$BRF_{(T+1)} = \left[\left(\alpha_{T-1}\right) \frac{(\text{USAGE DURING YEAR T})}{(\text{AVERAGE POPULATION IN YEAR T})} \right] + \left[(1-\alpha_{T-1})(BRF_T) \right]$$

The difference between ARRSES and the Navy's current method of computing BRFs is in the way smoothing weights (α) are selected. Under current procedures only two values are used as smoothing weights, one value for items with increasing BRFs and a second value for decreasing BRFs. The two values selected are based on policy considerations.

In ARRSES a different smoothing weight is used for each item. The values used are computed rather than selected and are based on each items usage and population data.

To determine the proper smoothing weight for an item, the following computations are made:

1. Compute the average usage per unit of population in year "T"(AU_T).

$$AU_T = \frac{\text{USAGE IN YEAR T}}{\text{AVERAGE POPULATION IN YEAR T}}$$

2. Compute the error (e) between the actual usage in year "T" and the BRF forecast for year "T". It should be noted that the BRF for year T was computed using data from year T-1.

$$\pm \; e_T = (AU_T) - (BRF_T)$$

NOTE: Error is positive (+) if AU > BRF

Error is negative (-) if AU < BRF

3. Compute a smoothed error (E) using the actual error (e), the smoothed error computed the previous year (E_{T-1}), and a smoothing weight B. In this study B = 0.2.

$$E_T = B\,(e_T) + (1-B)(E_{T-1})$$

4. Compute the absolute smoothed error (M) using the absolute value of the actual error ($|e|$), the absolute smoothed error computed the previous year (M_{T-1}), and the smoothing weight B.

$$M_T = B\,(|e_T|) + (1-B)(M_{T-1})$$

5. Compute a smoothing weight (α) by taking the absolute value of the quotient obtained when the smoothed error (E) is divided by the absolute smoothed error (M).

$$\alpha_T = \left| \frac{E_T}{M_T} \right|$$

It should be noted, see page D-1, that the smoothing weight based on data from year "T", is not used to compute the BRF for year T + 1. Instead, "α_T" is retained for one year and then used to compute the BRF for year T + 2,

(BRF_{T+2}). The literature on ARRSES reviewed for this study recommends that this procedure be followed "because ARRSES is often too responsive to changes".[1] Delaying the smoothing weight for one cycle, in this case one year, "allows the system to 'settle' a little and forecast in a more conservative manner".[2]

[1]Makridakis, S. and S. Wheelwright, 1978. Forecasting Methods and Applications, New York: John Wiley and Sons

[2]ibid

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13. ABSTRACT

The Navy uses an item's Best Replacement Factor (BRF) to estimate allowance requirements for items in the supply system. Each year BRFs are updated to reflect the latest usage and population data available. The current system computes a weighted average between the most recent BRF and the latest year of usage and population data to produce each item's new BRF. An alternative proposed method computes BRFs as the ratio of an item's total lifetime usage to the sum of the item's yearly average populations. A third method of computing BRFs which utilizes an Adaptive-Response-Rate Single Exponential Smoothing (ARRSES) procedure is also considered. These methods of computing BRFs are compared to determine which produces the most accurate estimates of future usage. Additionally, BRFs produced by the most promising method are used to build a series of Coordinated Shipboard Allowance Lists (COSALs) for three test ships. The COSALs are compared and differences in range, cost, stock churn and supply effectiveness caused by the different types of BRFs are identified, quantified and evaluated.

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