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STATISTICAL ANALYSIS OF PORT SYSTEMS REQUIREMENTS

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FINAL REPORT

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PSRPM is composed of computer programs PSP1 and PSP2. PSP1 uses DM-25's present electrical demand values in the prediction of future port electrical requirement specifications. PSP2 demonstrates, by using actual ship power usage data, covariance, and correlation, the potential for requirements forecasting.

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EXECUTIVE SUMMARY

This is a report of a study conducted under the Port Systems Project for the Naval Facilities Engineering Command. An objective of the Port Systems Project is to investigate methods of predicting the utility requirements of the port facilities that must be met to support future fleets. The analysis and results presented in this report are a refinement and extension of the work reported in A Methodology for Statistical Analysis of Port System Requirements. The fundamental advance offered by this study is that predictions can be based on recorded data rather than DM-25 capacity information.

This report starts with a brief overview of the first phase of the methodology development and continues with the technical approach and the principles of statistical theory applied. Examples are used to relate these principles to the analysis of electric power requirements as an aid in understanding the analytical process inherent in the Methodology. An overview of the analytical procedures that constitute the basis of the Port Systems Requirements Prediction Methodology is presented. Computer programs used to calculate statistics are appended. Finally the results achieved are presented.

The unique feature of this approach to port utility prediction is that it identifies and accommodates the contribution made by correlating the time usage of electric power consumption data among different ship classes. This results in non-zero correlation coefficients, which have an affect on the quality of the prediction. It is shown that as the number of ships using electrical power increases, the accuracy of the prediction is reduced.

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I. INTRODUCTION

1.0 Background.

The United States Navy is presently undergoing many changes. The fleet is being modernized to include 600 active ships equipped with the most modern systems available. The future port requirements of these ships will be different from those of today's mix of ships. Port Master Plans under development recognize that port facilities and services must be upgraded to meet the needs imposed by a changing fleet with changing operating procedures. It is reasonable to conduct research into existing planning procedures in order to identify modern methods which can be used to reflect fleet needs into the port master planning process. Current procedures are cumbersome and allow very little interaction for conducting tradeoff studies. This study, focused on analyzing and predicting electric power requirements, is a first step in developing these analytical procedures. It was conducted under the auspices of the Port Systems Project for the Naval Facilities Engineering Command.

1.1 Objective of the Port Systems Requirements Prediction Methodology (PSRPM).

The objective of PSRPM is the development of a statistically based procedure for analyzing and predicting port utility requirements. Eventually, it is envisioned that these procedures can be used as the basis of an interactive computer program which would permit an efficient analysis of alternative means of upgrading port utility systems.

This study was conducted in two parts. The first, described in Summary Report: An Application of the Port Systems Requirements Prediction Methodology (PSRPM) Using Electrical Measurements at Sewell's Point (12 - 76 to 1 - 77), established the feasibility and the basic methodology of a statistically based, computer aided forecasting process. For convenience, in this report, the first portion of this study will be referred to as Phase I. The extension of this study is the subject of this report and it will be referred to as Phase II.

1.2 Purpose.

The purpose of this report is to document the work accomplished to date in the development of the PSRPM Phase II.

1.3 Scope.

This document includes a summary of the work previously accomplished in PSRPM (Phase I) as well as a detailed description of the work accomplished in Phase II. A description of the concepts supporting the methodology and a review of the statistical procedures used in the methodology are presented first. Next, the application of these statistics and the computer programs associated with the statistical application are included. Finally, conclusions and recommendations based on the results of the Phase II investigation are discussed.

II. REVIEW OF PHASE I

2.0 Objective.

The objective of Phase I was to develop the foundation of a statistically based methodology which could be used as a tool by port designers to predict port utility requirements.

2.1 Technical Approach to Phase I.

Phase I assumed that the requirement for a port supplied utility to a group of ships could be estimated by statistical methods. If the utility requirement for each class was known and the probability that the ship would need this utility service was given, then a statisical prediction of the total utility requirement can be made. Phase I used demand data from NAVFAC DM-25 and ship populations and cold iron probabilities were derived from OPNAV INST 3111.14U and NAVSEC Report 6139-72-2 (1977), respectively. This information was used as input to create a computer simulated port activity model. This model was then used to compute the probability that a selected ship mix would create a demand for electric power greater than a port's deliverable capacity. This probability is plotted against capacity to yield a goal product on the form of Figure 1. Figure 2 models the Phase I activity flow which leads to the construction of the graphical representation that shows the probability of failure to meet the supplied demand.

Electric power was chosen as the initial utility to be studied because it can be easily measured and the data can be easily formatted for use in a mathematical model.

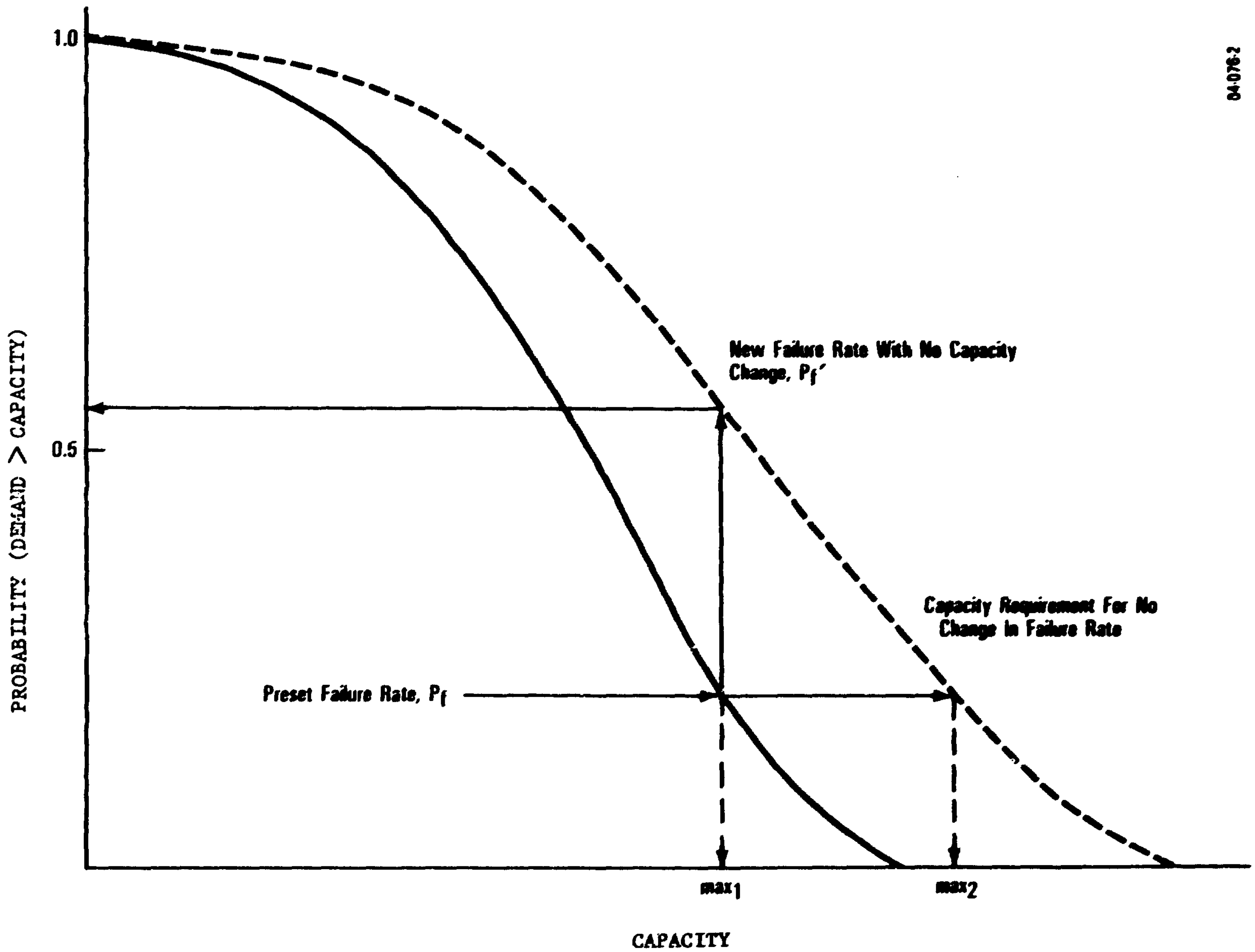

Figure 1. Primary PSRPM Output

DATA →	TREATMENT →	ANALYSIS →	OUTPUT
• Home Port Assignments • Cold Iron Probability • DM-25	• Summation • Calculate Means • Calculate Variances	• Monte Carlo Simulation • Central Limit Theorem	• Graph which presents the probability of demand exceeding capacity versus capacity • Mean and Standard Deviation of Demand for Electrical Power • Conclusions and Recommendations

Figure 2. PSRPM Phase I Activity Flow

2.2 Assumptions - Phase I.

The first phase of PSRPM development applied the following simplifying assumptions:

- The only utility analyzed was electric power, and each ship was assumed to be drawing its full design capacity for shore power in accordance with DM-25.
- No consideration was given to the time of day variations that would be expected for electric power demand.
- Ship class mix was determined by Monte Carlo (random number generation) simulation.
- The number of ships at cold iron in each ship class is assumed to be binomially distributed and independent of other classes.
- Resource demands per ship do not correlate with the number of ships present.

The logic associated with the computational process associated with PSRPM is presented in Figure 3.

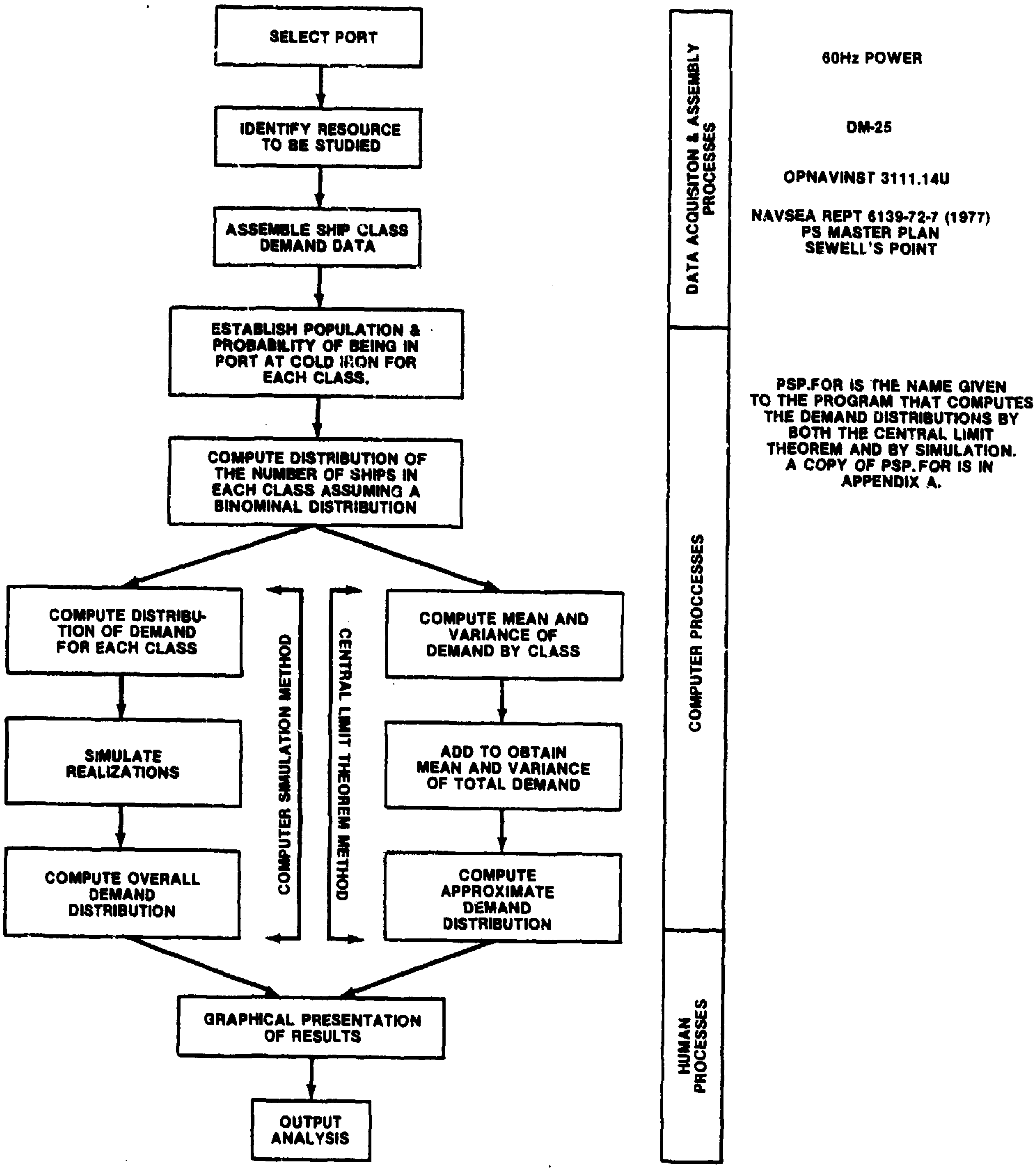

Figure 3. Port Systems Requirements Prediction Methodolgy Computational Process

2.3 Output of Phase I.

The primary output of Phase I is a methodology to produce a graphical representation of the probability that the demand for electric power will exceed a given capacity. The general format of this product was presented in Figure 1. The difference between the curves in the Y direction, with X constant, shows the change in the probability of failure to supply a required demand that will occur if the resource is not upgraded for future demands. The difference in the X direction, with Y constant, shows to what level of output the resource must be upgraded to maintain the current (if satisfactory) failure of probability to meet the total demand level.

Figure 4 is an example of the actual Phase I product.

2.4 Value of Phase I.

Phase I of the PSRPM demonstrated that the capability exists to take information regarding a port's utility demand and produce a tool usable in the forecasting of future utility demands. The study utilized design capacity information and applied proven statistical techniques to develop the methodology. The power of the PSRPM lies in the application of its fundamental product i.e., P (Demand >Capacity) versus Capacity curves. Specifically, Navy planners and port system designers can assemble alternative ship mixes, representing future fleet scenarios, and use the PSRPM to generate its goal product for each alternative. These products can then be used to predict and compare the power demand of each alternative ship mix. This is a major advantage over the DM-25 method of establishing pier capacity because it can represent ship types not yet constructed.

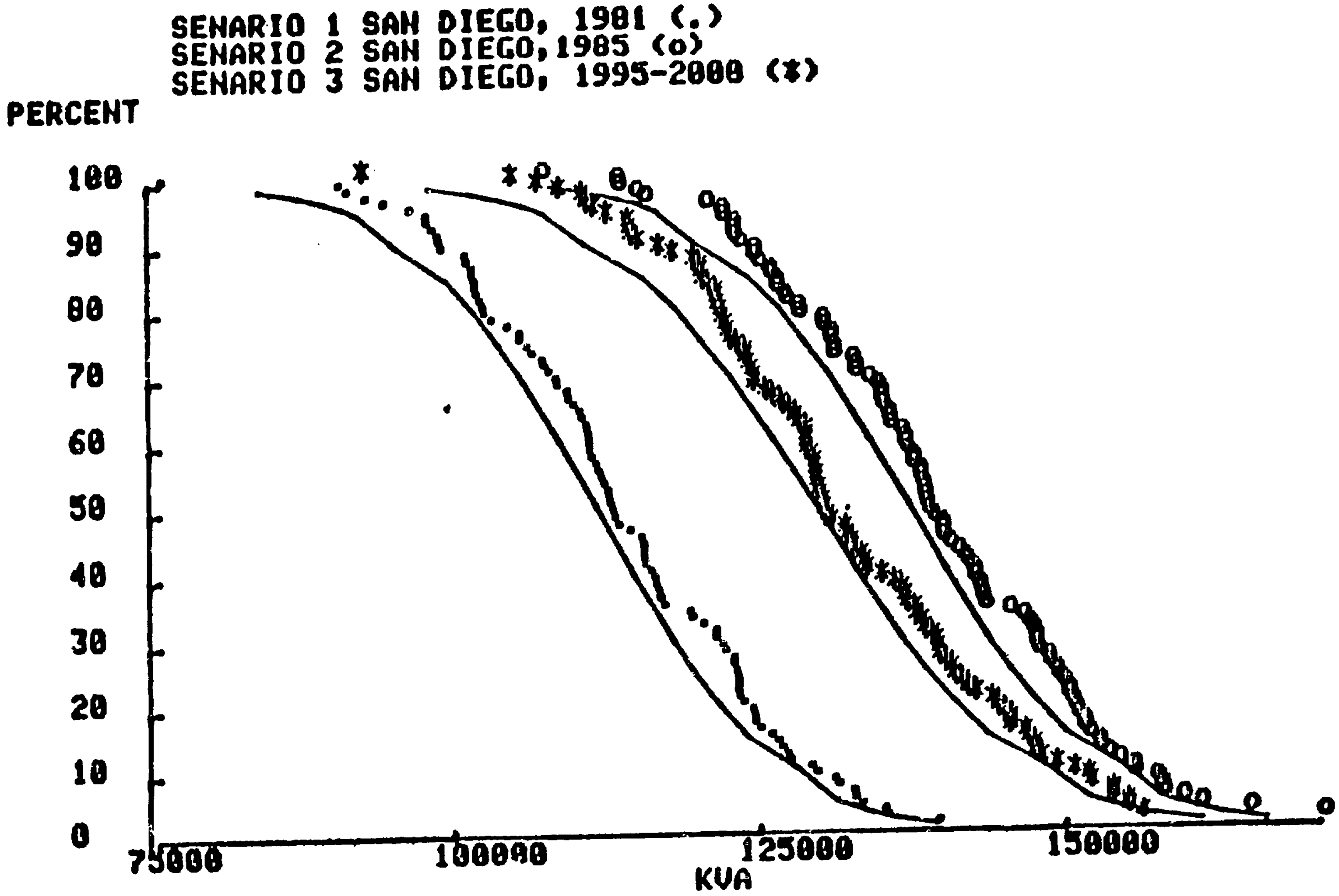

Figure 4. Probability of Exceeding a Specified Demand For Three Alternative Homeporting Plans, PSRPM - Phase I Output

III. PSRPM - PHASE II

3.0 Introduction

Phase II of the PSRPM provides a refinement to the methodology by using actual recorded electrical demand data as input to the computational process in place of DM-25 Present Demand data (design electrical capacity). Because there is variation in the demand when surveyed data is used, the statistical variance of each ship mix becomes increasingly important. Previous studies have based their prediction of overall power demand for an ensemble of ships on the calculation of individual ship means and individual variances. PSRPM Phase II estimates the overall power demand of a group of ships by calculating the individual ship means and the total ship ensemble variance. The governing basis for the ability to predict a ship mix's utility is the Central Limit Theorem.

3.1 Objective

Phase II of the PSRPM had the objective of applying the modeling techniques, developed in Phase I, to the analysis of electrical demand data obtained from Sewell's Point in 1977.

3.2 Scope of Phase II

Phase II of the PSRPM was written so the modeling techniques used in Phase I could be applied, with modification, to analyze actual electrical power utilization. The principle differences between the two phases are listed below:

- Phase II analyzed the actual three phase electrical power used by ships in port at cold iron. Phase I assumed each ship drew its full design capacity for shore power in accordance with DM-25.
- Phase I did not take into consideration any time of day variations which occur in real life. The Phase II analysis included a time variance factor based on the hourly electrical measurements to account for day to day fluctuations in power consumption.
- Phase I assumed that the resource demands per ship were not related to the number of ships present. Phase II recognizes that the electrical demand of one class of ships can in fact be correlated with demand for other classes. This affect is determined by the calculation of interclass and intraclass covariability of electrical power demand as a function of the total load.
- The Phase II analysis is based on one day "snapshots" since the mix of ships in the port varied from day to day.

The output of Phase II is identical in format to that of Phase I. However, the affect of using measurement data will be seen to cause an overall reduction in the predicted power demand for the case analyzed. Figure 5 displays the activity flow in Phase II.

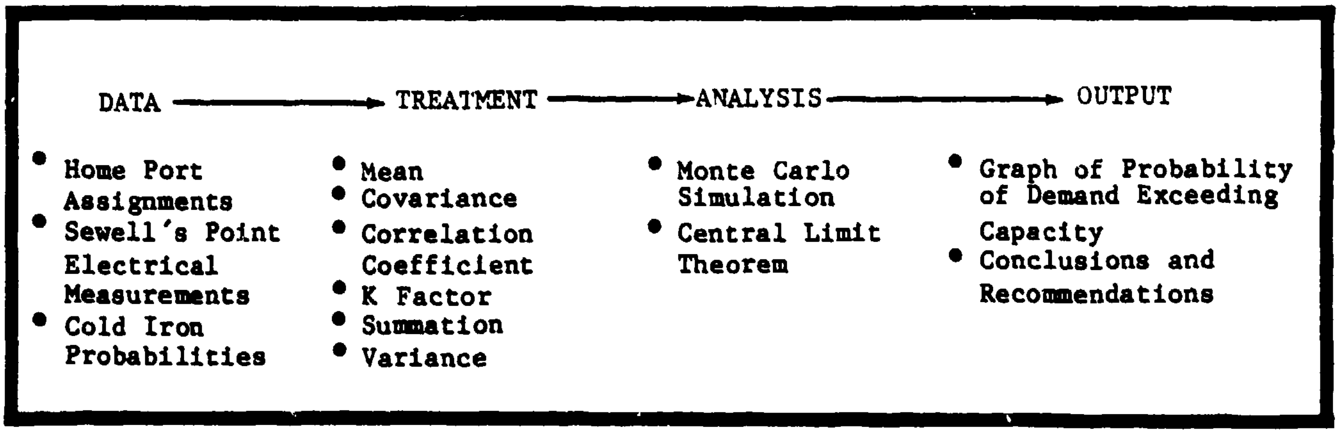

Figure 5. PSRPM Phase II Activity Flow

3.3 Phase II Process

The technical objective of the Phase II computational process was to derive the distribution of electic power demand for a group of ships of various classes. The process for obtaining this objective is outlined in Figure 6. The objective class distributions have been assumed to be normal and can be defined by knowing a mean KVA utilization and the variance in the utilization. Data for computing the distributions was obtained at Sewell's Point. From this data, ship specific mean hourly, mean daily, and hourly variance in KVA usage was determined. Next, the covariance associated with every combination of ships was calculated. This information constitutes what is necessary to generate a port mix of ships or realization.

A realization is generated by knowing the probability of a ship class being at cold iron and the number of ships in each class asigned to the port. A Monte Carlo Simulation determines the ship mix or ensemble of ship classes which make up each of the 100 realizations. Normal probability distributions representing the KVA demand per class were constructed based on the class mean and the ensemble variance. Ten different demand levels were determined for each class using a Monte Carlo Simulation and the probability distributions.

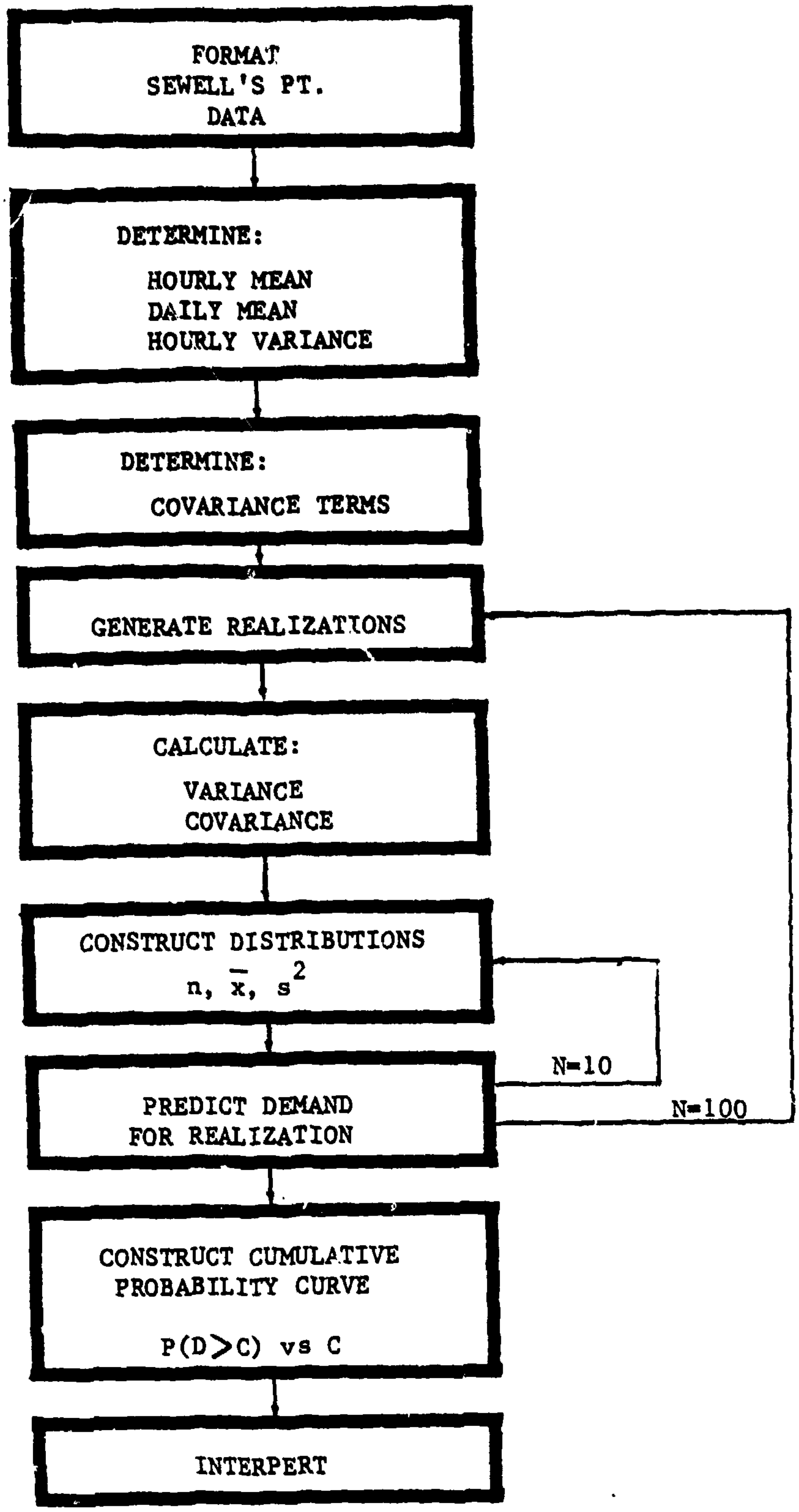

Figure 6. Phase II Computational Model and Logic Flow

The resulting 1000 port realizations of demand were used to construct a cumulative probability curve displaying the Probability of Demand Exceeding Capacity versus Capacity. This P(D>C) vs C curve and its interpretation form the basis of the PSRPM.

3.4 Assumptions

Enhancements to the second phase of the PSRPM analysis are based on changes made to the initial Phase I assumptions. The new assumptions are:

- Ship class electrical demand is based on actual measurements rather than DM-25 values,
- The hourly variations in electrical power usage are examined, and,
- The resource demands per ship are correlated with the number of ships present.

3.5 Sewell's Point Data

The ship class electrical demand information which was used in Phase II was obtained from measurements taken at Sewell's Point, Norfolk, Virginia in December 1976 through January 1977. Hourly samples of amperes were recorded at 450 - 470 volts AC for each ship present during the measurement time frame. The amperes were converted to kilovolt amperes (KVA) because components of electrical power transmission are usually rated in KVAs.

$$KVA = \frac{\text{Amperes} \times (\sqrt{3}) \times \text{Volts}}{1000}$$

Figures 7a and 7b are time/date tables of the electrical measurements for AOR-1 and CGN-38 ships. This data is representative of the data taken for the ships present each day at Sewell's Point.

ELECTRICAL SHORE POWER TO SHIPS OF AOR-1 "WICHITA" CLASS

	DATE	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
WEEKDAYS	DEC 20	600	700	700	700	700	700	700	750	750	800	750	750
	27	740	740	750	750	750	750	750	750	750	750	650	650
	21	780	790	780	790	730	750	750	750	750	750	725	780
	28	800	800	800	800	800	800	800	850	775	750	725	780
	22	600	650	650	650	650	650	650	650	750	750	700	750
	29	800	800	800	800	800	800	800	750	750	750	650	650
	23	700	700	700	700	700	700	700	700	800	700	700	700
	30	650	550	650	650	650	650	650	650	600	850	750	650
	24	650	650	650	650	650	650	650	750	650	750	750	735
	31	650	650	650	650	650	650	700	700	700	700	700	750
WEEKDAY AMPS		700	720	720	720	710	710	715	730	730	[illegible]	715	705
WEEKDAY KVA		545	560	560	560	555	555	555	570	570	550	555	550
WEEKEND/ HOLIDAYS	DEC 25	650	650	650	650	650	650	650	650	650	650	650	600
	JAN 1	650	650	650	650	650	650	650	650	650	650	650	700
	DEC 26	650	650	650	600	600	650	650	575	575	700	700	750
	JAN 2	700	700	700	600	600	600	650	650	650	650	650	650
WEEKEND/ HOLIDAYS AMPS		675	675	675	625	625	640	650	625	625	650	675	675
WEEKEND/ HOLIDAYS KVA		525	525	525	485	485	500	505	485	485	505	525	525

SHIP - SAVANNAH AOR-4
AMP READINGS AT 450 VOLTS AC

Figure 7a. Time/Date Table of Electrical Measurements for AOR-1

			1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
WEEKDAY	DEC	20	780	780	780	750	750	750	750	780	780	780	780	780
		27	800	750	650	850	750	700	650	650	650	650	650	650
		21	700	750	700	700	700	700	700	650	650	650	700	650
		28	780	780	780	780	780	780	780	730	730	730	740	740
		22	750	750	750	800	700	700	600	600	700	700	700	650
		29	800	750	650	850	750	700	650	650	650	650	650	650
		23	700	750	750	750	750	750	750	700	700	700	700	700
		30	700	700	750	750	650	750	650	650	650	650	650	650
		24	735	750	750	650	650	650	650	650	650	650	650	650
		31	750	700	650	650	650	650	650	700	700	700	700	650
WEEKDAY MEAN AMPS			750	745	720	755	715	715	685	675	685	685	685	685
WEEKDAY MEAN KVA			585	580	560	590	555	555	535	525	535	535	535	535
WEEKEND/HOLIDAY		25	600	650	650	650	650	700	650	700	600	600	650	650
	JAN	1	700	650	650	730	650	730	730	730	730	730	730	700
	DEC	26	750	750	700	700	700	700	700	700	700	700	700	650
	JAN	2	650	650	650	650	650	650	650	650	650	650	650	700
WEEKEND/HOLIDAY MEAN AMPS			675	675	675	675	675	695	675	695	675	675	675	675
WEEKEND/HOLIDAY MEAN KVA			525	525	525	525	525	540	525	540	525	525	525	525

Figure 7a. Time/Date Table of Electrical Measurements for AOR-1

ELECTRICAL SHORE POWER TO SHIPS OF CGN 38 "VIRGINIA" CLASS

	DATE		0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200
WEEKDAYS	DEC	22	1920	1850	1850	1850	1850	1900	2150	2500	2300	2350	2200	2500
		23	1950	1950	1950	1950	1950	2000	2000	2000	2000	2000	2600	2300
		24	1925	1925	1925	1800	1950	1950	1950	1850	1800	2250	2250	2200
		27	1600	1600	1600	1600	1600	1600	1600	1900	1900	2350	2270	2200
		28	1850	1850	1850	1800	1800	1800	1850	2425	2550	2400	2400	2400
		29	1850	1850	1850	1850	1900	1900	1900	2000	2050	2000	2400	2050
		30	1900	1850	1900	1850	1950	1900	1900	2500	2650	2450	2500	2500
		31	1900	1900	1900	1900	1900	1950	1900	1900	1900	1900	1850	2200
	JAN	3	1800	1800	1800	2075	1850	1850	1850	2400	2400	2600	2500	2450
		4	1900	1900	1900	1900	1950	1900	1800	1800	2400	2300	2200	2250
		5	2350	2350	2350	2350	2350	2350	2500	2300	2400	2500	2650	2600
		6	1950	2000	2000	2150	1950	1950	2475	2025	2350	2600	2650	2500
		7	2150	2200	2200	2100	2200	2450	2400	2450	2300	2300	2500	2650
MEAN KVA			1535	1535	1535	1545	1545	1565	1610	1720	1780	1840	1900	1890
WEEKENDS/HOLIDAYS														
	DEC	25	1950	1950	1950	1950	1950	1950	1950	2200	2200	1950	2000	1950
		26	1900	1900	1900	1900	1900	1900	1950	2000	1950	1900	1950	1900
	JAN	1	1900	1900	1900	1900	1900	1900	1900	2200	2000	1950	1900	1900
		2	1850	1850	1600	1600	1850	1850	1600	1600	1850	2150	1850	1850
		8	2300	2250	2300	2250	2300	2300	2300	2400	2350	2350	2350	2400
		9	2200	2200	2100	2200	2200	2200	2200	2200	2200	2200	2400	2700
		15	2150	2000	2000	2000	2000	2000	2000	2000	2030	2100	2050	1850
		16	2650	2550	2650	2650	2550	2650	2625	2700	2700	2800	2750	2800
MEAN KVA			1685	1655	1635	1640	1665	1670	1650	1725	1725	1735	1720	1730

SHIP:

VIRGINIA CGN-38

AMP READING AT 460 VOLTS AC

Figure 7b. Time/Date Table of Electrical Measurements for CGN-38

		DATE	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
WEEKDAYS	DEC	22	1400	2400	2350	2300	2300	2300	2450	2500	2300	1950	1950	1950
		23	2200	2200	2000	1950	1950	1950	1950	2200	1950	1950	1950	1950
		24	1950	1950	1950	1950	1950	2150	2300	1900	2050	1850	2000	1950
		27	2350	2180	2450	2450	2350	2350	2350	2050	2050	2050	2050	2050
		28	2150	2150	1950	2200	1900	1900	1900	1900	1850	1800	2100	1850
		29	2300	2100	2100	2350	2200	1900	1900	1850	1900	1900	1900	1900
		30	2450	2550	2400	2550	2000	2050	2000	2000	1950	1950	1900	1900
		31	2250	2200	2450	2150	2150	1900	1900	1900	1900	1900	1900	1900
	JAN	3	2500	2250	2000	1900	1900	1900	2000	2000	1900	2150	2100	2000
		4	2200	2200	1900	1900	2100	2100	2400	2500	2400	2400	2400	2300
		5	2600	2575	2375	2350	2300	2000	2350	2250	1950	1900	1900	1900
		6	2200	2000	2350	2600	2350	2250	2250	2200	2250	2250	2150	2100
		7	2700	2700	2700	2800	2800	2700	2700	2700	2650	2600	2550	2500
MEAN KVA			1860	1810	1775	1805	1730	1685	1735	1740	1670	1655	1645	1610
WEEKENDS/HOLIDAYS		25	1900	2200	1950	1950	1950	1950	1900	2200	2000	1950	1950	1900
		26	1950	1800	1800	1800	1850	1850	1850	1850	1600	1600	1600	1600
	JAN	1	1900	1900	1850	1875	1900	1875	1900	1900	1900	1900	1900	1900
		2	2100	2100	2100	1850	1850	1850	1850	1850	1850	1850	1850	1850
		8	2300	2350	2300	2200	2300	2200	2200	2150	2150	2200	2200	2100
		9	2700	2550	2350	2300	2400	2500	2200	2150	2150	22000	22000	2100
		15	1950	21000	1900	2000	2100	2375	2350	2350	2300	23000	2300	2600
		16	2650	2550	2500	2550	2650	2600	2050	20000	2250	2250	2250	2050
MEAN KVA			1740	1750	1670	1645	1700	1715	1625	1640	1650	1620	1620	1605

Figure 7b. Time/Date Table of Electrical Measurements for CGN-38

IV. PHASE II - TECHNICAL BACKGROUND

4.0 Introduction

The PSRPM was developed as a prediction technique for use by port planners in the updating of present ports and in the construction of new ones. The basis of this prediction methodology is the determination of the probability distribution function for the electrical demand of a group of ships. This distribution can then be used to calculate the probability of the demand exceeding the facility's capacity. This is the basis for predicting the power demand of a given group of ships.

A distribution function is defined by its mean, which locates the center, and by its variance which determines the shape. The variances and means of electrical demand of several ship classes were calculated from the data recorded at Sewell's Point 1976. Since the variance describes the shape of the distribution, its accuracy determines the quality of the prediction which can be made from the PSRPM. This study shows that there is a correlation associated with the ships' time of electrical usage. The existance of a non zero correlation coefficient, by definition, establishes a covariance term which must be included when calculating the variance in electrical demand caused by a group of ships. The contribution of this term to total demand is not intuitively obvious. It will be seen that the covariance term will impact the accuracy of a prediction system based on statistical processes.

The methodology developed herein utilizes particular statistical techniques which provide significantly more information than simply the maximum electrical capacity required at Naval ports. This section is devoted to the explanation of each of these techniques and their relevance to the PSRPM. Included are discussions on the mean, the variance, the covariance, the standard deviation, and the correlation coefficient. Also included is a review of the conservative factor (K) which was developed as part of Phase II of the PSRPM. The details of this factor are addressed in A Comparison of Two Methods for Estimating the Electrical Supply Capacity Required for Piers and Drydocks.

4.1 The Normal Distribution

Figure 5 displays a graph of a normal density function, sometimes called the Standard Normal Curve. The shape of the normal curve is defined by the magnitude of the mean and the standard deviation, or the square root of the variance. Plus and minus one standard deviations from the mean defines the inflection points of the curve. Within this area lies 68.27% of the observations.

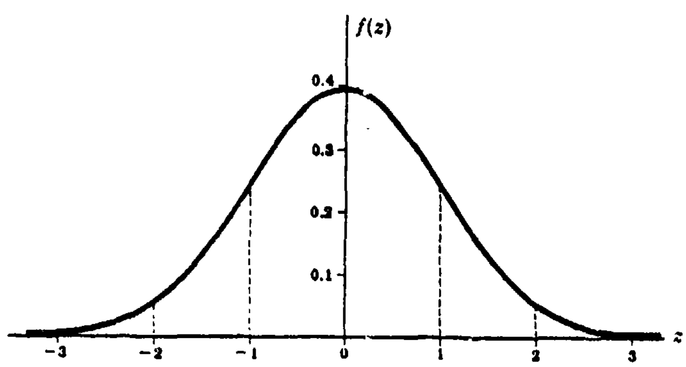

Figure 8. Standard Normal Curve

When the variance in a set of data changes, the overall shape of the curve changes. Figure 9 shows the effect of increasing variance on the shape of the distribution curve. Phase II is interested in the shape of the normal curve

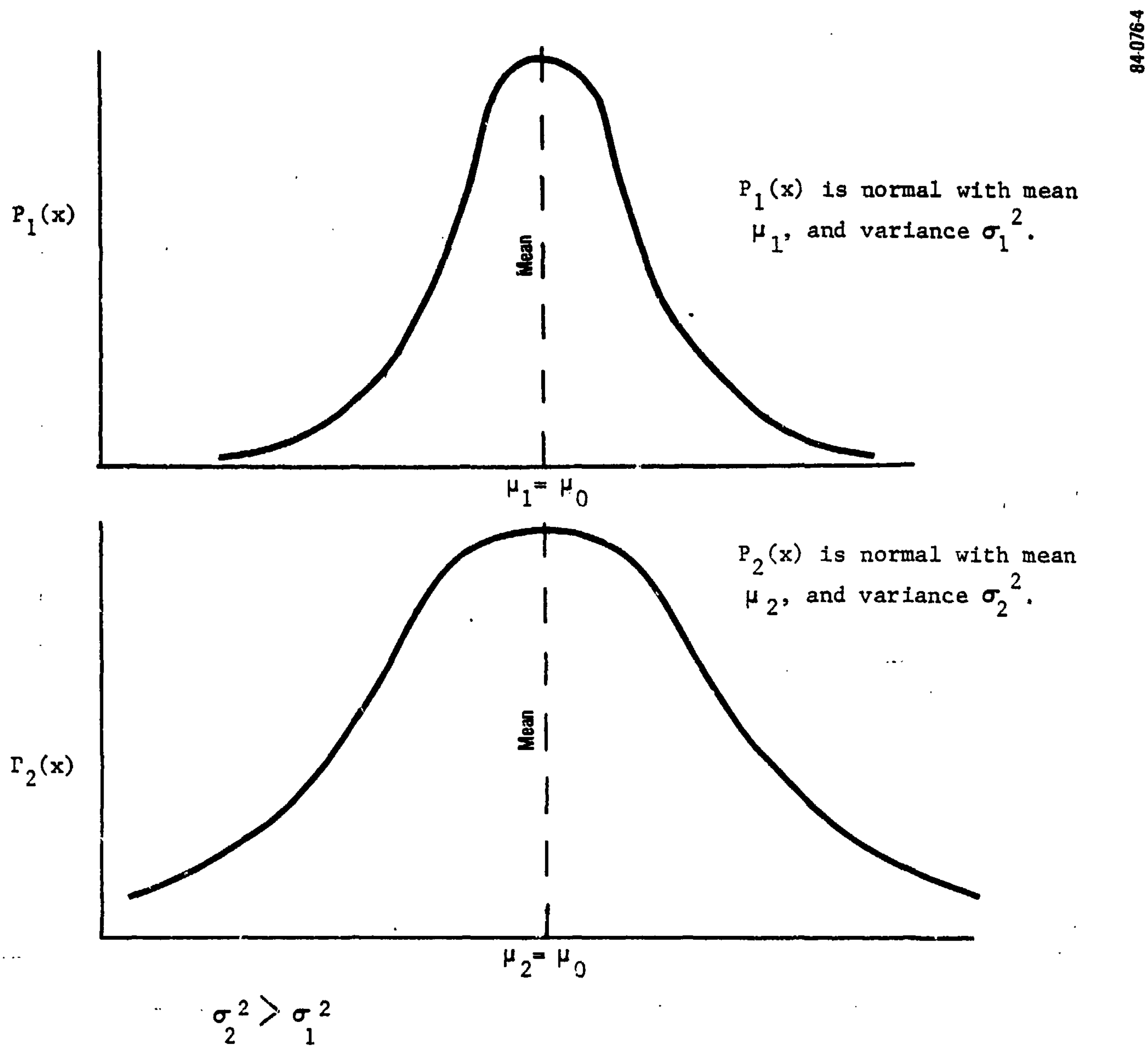

Figure 9. The Effect of Increasing Variance

when the variance increases. The change in the shape of the curve, particularly in the wings, reveals the degree of prediction accuracy inherent to the methodolgy. Also the new shape redefines the maximum electrical demand for a given mix of ships.

4.2 Mean

One parameter of an entire group or population that is of interest is the population mean, μ, because it is one method used to describe the population's center. If every item, or ship in the case of this report, were totally accessible and measured its mean would be computed by the formula:

$$\mu = \sum_{i=1}^{N} \frac{x_i}{N} \qquad (1)$$

where μ = population mean

$\sum_{i=1}^{N} x_i$ = sum of all values of the variable of interest for the whole population

N = Number of elements in the population

Statistical inference about a population mean requires information obtained from samples of the population. In the case of the Sewell's Point data the information gathered are samples of the population. The sample average, $\overline{x}$, which is analogous to a population mean is defined as:

$$\overline{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

where $\overline{x}$ = value of the average (2)

$\sum_{i=1}^{n} x_i$ = sum of samples

n = number of samples

4.2.1 Summation of Means

If two or more sets of data of equal sample size have been collected, the mean of the sum $(\overline{x_1 + x_2})$ is equal to the sum of the means. Example 1 is an example of the application of this statement. Data was extracted from the weekday mean KVA line of Figures 7a and 7b.

Example 1:

	AOR-1	CGN-38	(AOR-1 + CGN-38)
$\sum$ Observations	13300 KVA	40720 KVA	54020 KVA
Number of Observations	24	24	24 pairs
Mean	554.7 KVA	1696.67 KVA	2250.82 KVA

554.16 + 1696.67 = 2250.82 = 2250.82 KVA

4.3 Variance

A second population parameter that is of interest in this study is σ^2 or the population variance. Variance is the measure of the dispersion of a population. The variance within a population is the sum of the squares of the difference between each particular observation and the mean. This sum is then divided by the total number of observations.

$$\sigma^2 = \sum_{i=1}^{N} \frac{(x - \mu)^2}{N} \qquad (3)$$

When just a sample of information about the population is known, then the sample variance, s^2, is defined as:

$$s^2 = \sum_{i=1}^{n} \frac{(x - \bar{x})^2}{n - 1} \qquad (4)$$

The n-1 is used so that the sample variance will be an unbiased estimator of the population. It is the range of recorded values that is of interest in PSRPM because it is the upper portion of this range that defines the maximum demand of electrical power for an ensemble of ships. Hence, from this maximum demand, design specifications for future ports and ship mixes can be developed and/or evaluated.

4.3.1 Summation of Variance

Section 4.2.1 stated that the mean of the sum was equal to the sum of the means. In the case of variance, the sum of two variances may not equal the variance of the entire sample. Example 2 uses the same data as was used in Example 1 to show that the sum of two variances may not equal the variance of the sum.

Example 2: Using Equation 3.

$$\text{Variance}_{(AOR)} + \text{Variance}_{(CGN)} \neq \text{Variance}_{(AOR + CGN)}$$

$$275.9058 + 14375.36 \neq 340296.4$$

$$14651.66 \neq 340296.4$$

To permit the computation of the variance of the sum of demands such as the AOR and CGN, the concept of covariance shall be introduced.

The relationship between two variables may, under certain conditions (normal correlation) be described by way of a single number, which is a symmetrical function of the observations. This single number is covariance and is typically defined in the equation:

$$s_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \overline{x})(y_i - \overline{y}) \tag{5}$$

where $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ denote the observed values of x and y. The sum of the products of the deviations from the mean may be expressed as:

$$\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y}) = \sum_{i=1}^{n} x_i y_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i\right) \tag{6}$$

The variance of the sum of AOR and CGN observations can be expressed as Equation 7.

$$s^2_{(AOR + CGN)} = \sum_{i=1}^{24} \frac{[(AOR_i + CGN_i) - (\overline{AOR} + \overline{CGN})]^2}{n - 1} \qquad (7)$$

In Equation 7 the observed mean values of AOR and CGN are the KVA readings taken at common times, (i.e., 0100, 0200, 0300, ..., 2400). The term $(\overline{AOR} + \overline{CGN})$ is the summation of the means of the readings and is not dependent on the time in which the readings were taken. A further expansion of Equation 7 reveals:

$$s^2_{(AOR + CGN)} = \sum_{i=1}^{24} \frac{[(AOR_i - \overline{AOR}) + (CGN_i - \overline{CGN})]^2}{n-1}$$

$$= \sum_{i=1}^{24} \left(\frac{(AOR_i - \overline{AOR})^2}{n - 1} + \frac{2(AOR_i - \overline{AOR})(CGN_i - \overline{CGN})}{n - 1} + \frac{(CGN_i - \overline{CGN})^2}{n - 1} \right) \qquad (8)$$

Recall that the variance of the AOR observations is $\sum_{i=1}^{24} \frac{(AOR_i - \overline{AOR})^2}{n - 1}$

and the variance of the CGN observations is $\sum_{i=1}^{24} \frac{(CGN_i - \overline{CGN})^2}{n - 1}$.

The middle term in Equation 8 is in the form of the covariance. Refer to Equation (5).

$$\sum_{i=1}^{24} \frac{(AOR_i - \overline{AOR})(CGN_i - \overline{CGN})}{n - 1} = \text{covariance} \qquad (9)$$

The total variance of the sum of the hourly KVA usages can be determined through the construction of a covariance table which is a convenient way of organizing the variance and covariances. The present example illustrates this fact.

Remembering:

$$s^2_{(AOR)} = \sum_{i=1}^{24} \frac{(AOR_i - \overline{AOR})^2}{n - 1}$$

$$s^2_{(CGN)} = \sum_{i=1}^{24} \frac{(CGN_i - \overline{CGN})^2}{n - 1}$$

$$COV_{(AOR,\ CGN)} = \sum_{i=1}^{24} \frac{(AOR_i - \overline{AOR})(CGN_i - \overline{CGN})}{n - 1}$$

The covariance table is written as:

$$\begin{pmatrix} s^2_{(AOR)} & COV_{(AOR,\ CGN)} \\ COV_{(CGN,\ AOR)} & s^2_{(CGN)} \end{pmatrix}$$

The COV of an AOR and a CGN is, by its definition, equal to that of the CGN and AOR. Therefore, using Equation (6):

$$s^2(AOR + CGN) = s^2(AOR) + 2COV(AOR, CGN) + s^2(CGN) \quad (10)$$

which is the sum of the terms in the above mentioned covariance table.

The calculation of Equation (6) is repeated for every possible combination of ship classes in order to construct the master covariance table. Ships are even compared to other ships in the same class to determine intraclass covariances (as opposed to interclass covariances).

4.4 Standard Deviation

This statistic aids in the description of the width of the distribution curve. On a normal curve, 1 standard deviation, s, on either side of the distribution mean defines the curve's inflection points. Between $\bar{x} + s$ and $\bar{x} - s$ lies almost 68% of the observed data, and between $\bar{x} + 3s$ and $\bar{x} - 3s$ lies 99.9% of the data.

The variance of a sample grouping of data carries the units of the data squared (KVA^2) and is, by definition, the square of the standard deviation. The covariance is difficult to interpret as a measure of the relationship between two variables because its value is given in terms of the observation's units. However, dividing the covariance (KVA^2 in this study) by the product of the standard deviations, or square root of the product of the variances (KVA^2), a number which is dimensionless and independent of the units of measure is created. This number is the correlation coefficient.

4.5 Correlation Coefficient

Correlation is used to determine the degree of association between two items. The statistic r is called the sample correlation coefficient. To account for the fact that electrical usage generally peaks during particular morning and afternoon hours, the PSRPM utilizes the statistical techniques involved with correlation. In all cases $-1 \leq r \leq 1$. If $r = -1$, there is a perfect negative relationship and if $r = +1$, there is a perfect positive relationship. In the case of the PSRPM, the correlation coefficient is a normalized value indicating the strength and character of the relationship of electrical power usage as a function of time between any pair of ships. If the correlation is positive the implication is that the maximum and minimum usages occur at approximately the same time; if the correlation is negative, the maximum of the usage of one ship occurs approximately when that of the other is at a minimum. Thus a negative correlation has the effect of reducing the variability in the sum of the usages. Figure 10 shows the resulting correlation table for the ships present at Sewell's Point during the survey. The average weekday and weekend correlation coefficients are .75 and .22 respectively.

The following shows an example of the computation of a correlation coefficient. The ships compared are once again the AOR-1 and CGN-38.

Equation 11 is commonly used to determine the correlation coefficient.

Example 3:

$$r = \frac{s_{xy}}{\sqrt{s_{xx}\, s_{yy}}} = \frac{COV_{xy}}{s_x\, s_y} \qquad (11)$$

$$s_{xy} = n\sum_{i=1}^{n} xy - \sum_{i=1}^{n} x \sum_{i=1}^{n} y$$

$$= n \sum_{i=1}^{24} [(AOR_i)(CGN_i)] - \sum_{i=1}^{24} (AOR_i) \sum_{i=1}^{24} (CGN_i)$$

and

$$s_{xx} = n\sum_{i=1}^{n} x^2 - \left(\sum_{i=1}^{n} x\right)^2$$

$$= n \sum_{i=1}^{24} (AOR_i^2) - (\sum_{i=1}^{24} AOR_i)^2$$

and

$$s_{yy} = n \sum_{i=1}^{n} y^2 - (\sum_{i=1}^{n} y)^2$$

$$= n \sum_{i=1}^{24} (CGN_i^2) - (\sum_{i=1}^{24} CGN_i)^2$$

$$\sum_{i=1}^{24} AOR_i = 13300 \qquad \sum_{i=1}^{24} (AOR_i)^2 = 7377250$$

$$\sum_{i=1}^{24} CGN_i = 40720 \qquad \sum_{i=1}^{24} (CGN_i)^2 = 69418900$$

$$\sum_{i=1}^{24} (AOR_i)(CGN_i) = 22579225$$

$$s_{xy} = 24\ (22579225) - (13300)(40720) = 325400$$

$$s_{xx} = 24\ (7377250) - (13300)^2 = 164000$$

$$s_{yy} = 24\ (69418900) - (40720)^2 = 7935200$$

Then, $$\frac{325400}{\sqrt{(164000)(7935200)}} = .285 = \text{correlation coefficient}$$

The circled correlation coefficients in Figure 10 show a computer generated value of $r = .28$.

LEGEND FOR FIGURE 10.

1.	AD-14	2.	AD-37	3.	AFS-1	4.	AO-143	5.	AOR-1	6.	AR-5	7.	AS-36
8.	ASR-21	9.	ATF-69	10.	CG-16	11.	CGN-38	12.	CV-59	13.	CV-67	14.	DD-193
15.	DD-963	16.	DDG-2	17.	DDG-37	18.	FF-1037	19.	FF-1052	20.	LCC-19	21.	LKA-113
22.	LPA-248	23.	LPD-4	24.	LPD-12	25.	LPD-13	26.	LPH-2	27.	LST-1179	28.	SSN-637

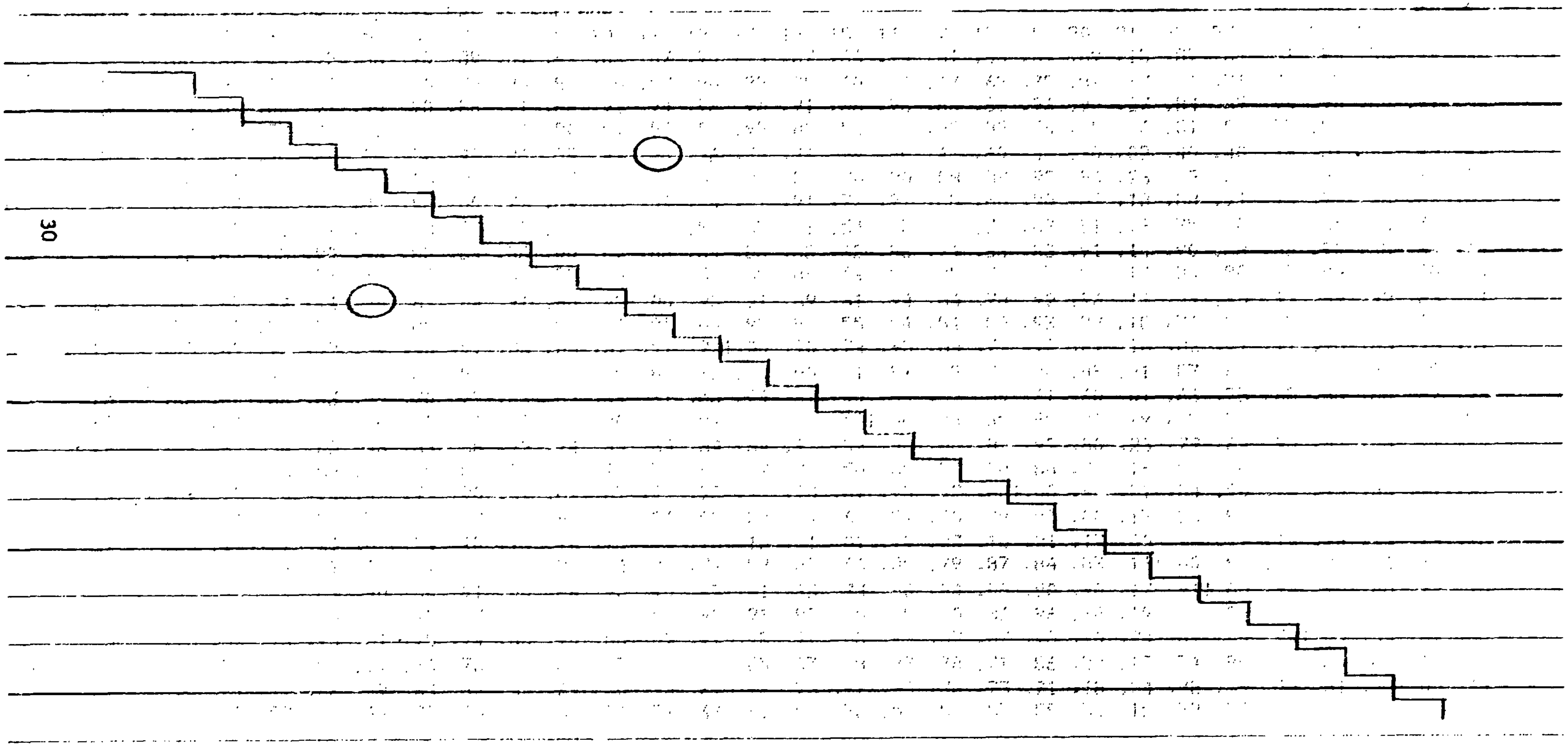

Figure 10. Master Correlation Table
(Weekdays)

Figure 10. Master Correlation Table
(Weekends)

Furthermore, the accuracy of the prediction is based on the square of the number of ships present in the model. For example, the number of ships in the model defines the dimensions of the covariance table. N ships produces a N x N table. The numbers on the diagonal define the variances and the number on the off diagonal are the covariances. We have:

N Variances, and

N^2 - N Covariances

The variance of the sum of demands would be:

$$\sigma^2 (x_1 + x_2 + \ldots + x_n) = N\overline{V} + (N^2 - N)\overline{COV}$$

where $\overline{V}$ is the average variance and $\overline{COV}$ is the average covariance.

The magnitude of the covariances may be small but as the number of ships, N, increases so does the total variance. The increase can be seen to vary as the square of the number of ships. As the variance increases (as N increases) the distribution curve widens and the area under the wings is increased predictability becomes less precise. See Figure 11.

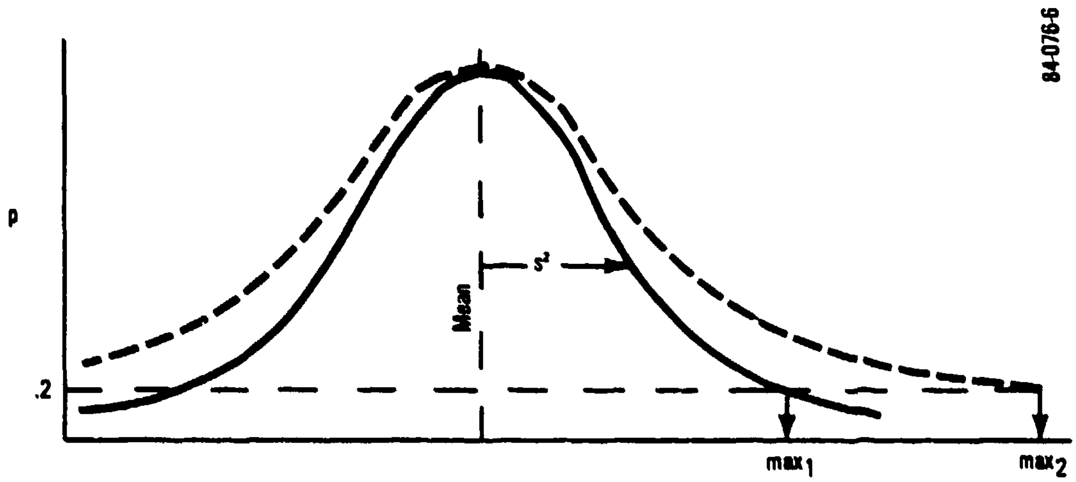

Figure 11. Influence of Covariance on Maximum Resource Specification

The value of the correlation coefficients not only gives an idea of the tendency of the ships to have corresponding peak and lull periods of power utilization, but they are indicators of the predictibility of distribution of the maximum demand made by the ships. In order to make the statement that r is a measure of the predictibility of total demand consider the following:

$$r = \frac{\text{covariance}}{\sqrt{s^2(x)\ s^2(y)}} \qquad (12)$$

Assume ship x and ship y have a variance of 1 and a correlation coefficient of .5. The covariance would then equal:

$$r\sqrt{s^2(x)\ s^2(y)} = .5$$

and the sum of the terms of the covariance table would be:

$$\begin{pmatrix} 1 & .5 \\ .5 & 1 \end{pmatrix} = \sigma^2(x + y) = 3$$

If the correlation coefficient were .1 instead of .5 (keeping the individual variances = 1), the variance of the sum would equal 2.2 which would change the overall shape of the final cumulative probability distribution curve. The overall shape of the distribution of the total demand for a resource, and hence its predictibility, has a major effect on the specifications of the capacity of the resource since specifications which are defined by normal distributions are normally stated in a particular number of standard deviations about the mean ($\bar{x} \pm ns$).

4.6 Conservativeness Factor

It is known from experience that the resource consumption of a group of ships is less than the capacities of all the individual ships added together. This is attributed to both variation in an individual ship's demand and coincidental loading between ships, leading to a certain amount of diversity in the loading between two or more ships serviced from the same transformer. The DM-25 method accounts for this effect by taking the maximum designed electrical capacity of the various ships and reducing their sum by multiplier (called a diversity factor) dependent upon the number and class of ships serviced by the transformer.

The PSRPM calculates a diversity factor, not as a mechanism for accommodating the diversity effect as with the use of the DM-25 diversity factor, but rather as an illustrative parameter. The actual capacity itself is predicted by the PSRPM and the diversity factor illustrates how the capacity for a ship group relates to the sum of the capacities for the individual ships.

The diversity factor depends strongly on the criterion established for relating the capacity to the parameters of the demand distribution. This was accomplished through a number defined as the conservativeness factor (K) which is the number of standard deviations above the mean demand at which the capacity requirement is set. The larger the K factor, the more conservative the estimate of required capacity.

The evolution of the conservativeness factors for the PSRPM may be found in greater detail in A Comparison of Two Methods for Estimating the Electrical Supply Capacity of Navy Piers, 1/83. As a result of this study, the recommendation was made to continue the DM-25 process as a direct, simple, and conservative process for designing the power capacity of permanent installations.

V. PSRPM - PHASE II COMPUTER PROGRAMS

5.0 Introduction

Phase I of the PSRPM utilized a suite of five data base programs and two data analysis programs in addition to computer aided graphics package to generate the probability (Demand > Capacity) versus Capacity curves. Phase II reduced the number of data base programs to one, and modified one of the data analysis programs to permit future refinements.

5.1 PSP2 FORTRAN Programs

The program PSP2 is an enhanced version of program PSP1. A listing of PSP1 may be found in the Summary Report: An Application of the Port Systems Requirements Prediction Methodology (PSRPM) Using Electrical Measurements Recorded at Sewell's Point (12-76 to 1-77). PSP2 generates realizations similar to PSP1 but substitutes electrical usage data obtained from the observations made at Sewell's Point in place of DM-25's Present Demand values in calculating the total KVAs used. There is one data base program and one data analysis program which assist PSP2. Complete listings of the programs and samples of the data files are located in Appendix A.

5.1.1 Data Base Program

The surveyed data was formatted for FORTRAN and entered into a program called KVADB. This program created the data base KVA.DBS (KVA Data Base) which contains the ship class, number of days in port, date, daily hourly KVA readings, and mean hourly KVA usage, and summed mean hourly KVA usage. The data base distinguishes weekday from weekends by the use of a minus sign in column 1. Appendix A contains a printout of KVADB and KVA.DBS, and Figure 12 presents a schematic of this logic.

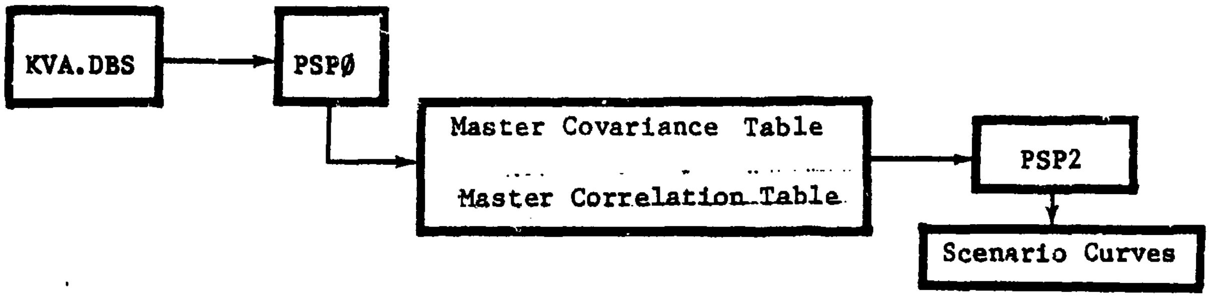

Figure 12. Data Base Logic Flow

5.1.2 Data Analysis Program

A program separate from PSP2, named PSPØ was created to construct the covariance and correlation tables. PSPØ was made separate from PSP2 to aid in the incoropration of refinements to the statistical techniques which were used to calculate values in each table. Refinements and changes to procedures can simply be made to PSPØ without having to modify the master PSP2 program.

Figure 13 provides a view of the computer process. PSPØ uses data from KVA.DBS to generate the Master Covariance and Correlation Tables. Information from the KVA.DBS and these tables is inputted to PSP2 which generates the data points, from the realizations, for the P(D>C) vs. C curves for different port scenarios.

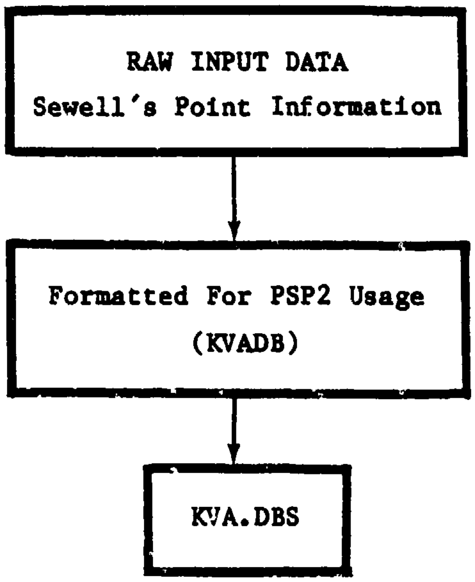

Figure 13. Computer Process

VI. APPLICATION

6.0 Introduction

All of the statistics discussed in Section IV have a relevance to the prediction of the overall demand. The mean for each class of ships defines the center of the distribution for that class and the total variance defines the shape of the distribution in the form of the standard deviation. The correlation coefficient provides an indication of the degree of association between the peak electrical demand periods of any pair of ships.

6.1 Objective

The objective of this section is to discuss the application of the statistics presented in Section IV and to present the importance of the contribution of the covariance in the shaping of the distribution curve.

6.2 Covariance

Hourly KVA readings were taken over the period of several days for 28 ships in 22 classes at Sewell's Point. This data was used in this study to demonstrate a methodology to predict future port utilization requirements. PSRPM is a demonstration of a particular type of prediction methodology which utilizes the means and variances associated with the hour to hour and day to day electric power consumption utilizations. The computation of the sum of the variances which define the future requirements is not a trivial task. In order to simplify the computation a physical manipulation of the terms in the quadradic equation (see Equation 7) permits the summation of the variances and covariances belonging to two sets of ship data. Executing this procedure for every pair of ships (784 Phase II combinations) results in a 28 x 28 covariance table. The Master Covariance Table is presented in Figure 14.

COVARIANCE MATRIX FOR WEEKDAYS WAS AS FOLLOWS

	AD-14	AD-37	AFS-1	AD-143	AOR-1	AR-5	AS-36	ASR-21	ATF-69	CG-16
AD-14	0.134E 05	0.191E 05	0.108E 05	0.259E 04	0.218E 04	0.197E 05	0.315E 05	0.506E 04	0.628E 03	0.849E 04
AD-37	0.191E 05	0.352E 05	0.163E 05	0.403E 04	0.145E 04	0.251E 05	0.419E 05	0.827E 04	0.906E 03	0.127E 05
AFS-1	0.108E 05	0.163E 05	0.990E 04	0.232E 04	0.197E 04	0.169E 05	0.265E 05	0.443E 04	0.512E 03	0.763E 04
AD-143	0.259E 04	0.403E 04	0.232E 04	0.577E 03	0.428E 03	0.391E 04	0.631E 04	0.110E 04	0.126E 03	0.185E 04
AOR-1	0.218E 04	0.145E 04	0.197E 04	0.428E 03	0.238E 04	0.527E 04	0.705E 04	0.638E 03	0.110E 03	0.137E 04
AR-5	0.197E 05	0.251E 05	0.169E 05	0.391E 04	0.527E 04	0.355E 05	0.543E 05	0.726E 04	0.912E 03	0.127E 05
AS-36	0.315E 05	0.419E 05	0.265E 05	0.631E 04	0.705E 04	0.543E 05	0.913E 05	0.114E 05	0.148E 04	0.218E 05
ASR-21	0.506E 04	0.827E 04	0.443E 04	0.110E 04	0.638E 03	0.726E 04	0.114E 05	0.238E 04	0.251E 03	0.333E 04
ATF-69	0.628E 03	0.906E 03	0.512E 03	0.126E 03	0.110E 03	0.912E 03	0.148E 04	0.251E 03	0.340E 02	0.438E 03
CG-16	0.849E 04	0.127E 05	0.763E 04	0.185E 04	0.137E 04	0.127E 05	0.218E 05	0.333E 04	0.438E 03	0.710E 04
CGN-38	0.230E 05	0.368E 05	0.212E 05	0.522E 04	0.315E 04	0.352E 05	0.577E 05	0.100E 05	0.116E 04	0.175E 05
CV-59	0.341E 05	0.549E 05	0.310E 05	0.756E 04	0.584E 04	0.521E 05	0.824E 05	0.148E 05	0.159E 04	0.235E 05
CV-67	0.269E 05	0.414E 05	0.234E 05	0.548E 04	0.481E 04	0.421E 05	0.687E 05	0.103E 05	0.124E 04	0.187E 05
DD-931	0.326E 04	0.474E 04	0.293E 04	0.684E 03	0.575E 03	0.535E 04	0.892E 04	0.127E 04	0.159E 03	0.243E 04
DD-963	0.902E 04	0.134E 05	0.678E 04	0.151E 04	0.167E 04	0.156E 05	0.257E 05	0.307E 04	0.430E 03	0.541E 04
DDG-2	0.833E 04	0.120E 05	0.731E 04	0.173E 04	0.149E 04	0.129E 05	0.209E 05	0.325E 04	0.390E 03	0.575E 04
DDG-37	0.199E 05	0.268E 05	0.185E 05	0.433E 04	0.496E 04	0.353E 05	0.568E 05	0.748E 04	0.918E 03	0.152E 05
FF-1037	0.930E 03	0.109E 04	0.793E 03	0.186E 03	0.274E 03	0.158E 04	0.226E 04	0.351E 03	0.454E 02	0.589E 03
FF-1052	0.488E 04	0.697E 04	0.448E 04	0.105E 04	0.107E 04	0.818E 04	0.128E 05	0.200E 04	0.228E 03	0.347E 04
LCC-19	0.142E 05	0.218E 05	0.126E 05	0.313E 04	0.207E 04	0.218E 05	0.364E 05	0.611E 04	0.735E 03	0.105E 05
LKA-113	0.545E 04	0.807E 04	0.691E 04	0.158E 04	0.262E 03	0.112E 05	0.140E 05	0.167E 04	0.211E 03	0.286E 04
LPA-248	0.510E 04	0.616E 04	0.415E 04	0.960E 03	0.978E 03	0.829E 04	0.131E 05	0.182E 04	0.260E 03	0.350E 04
LPD-4	0.562E 04	0.776E 04	0.484E 04	0.113E 04	0.106E 04	0.902E 04	0.149E 05	0.212E 04	0.279E 03	0.415E 04
LPD-12	0.820E 04	0.113E 05	0.725E 04	0.172E 04	0.146E 04	0.134E 05	0.218E 05	0.331E 04	0.396E 03	0.581E 04
LPD-13	0.824E 04	0.115E 05	0.706E 04	0.167E 04	0.185E 04	0.133E 05	0.211E 05	0.310E 04	0.392E 03	0.552E 04
LPH-2	0.407E 04	0.699E 04	0.363E 04	0.902E 03	0.392E 03	0.587E 04	0.961E 04	0.186E 04	0.202E 03	0.284E 04
LST-1179	0.465E 04	0.515E 04	0.384E 04	0.854E 03	0.130E 04	0.850E 04	0.133E 05	0.131E 04	0.219E 03	0.319E 04
SSN-637	0.860E 04	0.922E 04	0.695E 04	0.142E 04	0.266E 04	0.162E 05	0.243E 05	0.281E 04	0.457E 03	0.560E 04

Figure 14. Master Covariance Table (Weekdays)

COVARIANCE MATRIX FOR WEEKDAYS WAS AS FOLLOWS

	CGN-38	CV-59	CV-67	DD-931	DD-963	DDG-2	DDG-37	FF-1037	FF-1052	LCC-19
AD-14	0.230E 05	0.341E 05	0.269E 05	0.326E 04	0.902E 04	0.833E 04	0.199E 05	0.930E 03	0.488E 04	0.142E 05
AD-37	0.368E 05	0.549E 05	0.414E 05	0.474E 04	0.134E 05	0.120E 05	0.268E 05	0.109E 04	0.697E 04	0.218E 05
AFS-1	0.212E 05	0.310E 05	0.234E 05	0.293E 04	0.678E 04	0.731E 04	0.185E 05	0.793E 03	0.448E 04	0.126E 05
AO-143	0.522E 04	0.756E 04	0.548E 04	0.684E 03	0.151E 04	0.173E 04	0.433E 04	0.186E 03	0.105E 04	0.313E 04
AOR-1	0.315E 04	0.584E 04	0.481E 04	0.575E 03	0.167E 04	0.149E 04	0.496E 04	0.274E 03	0.107E 04	0.207E 04
AR-5	0.352E 0[illegible]	0.521E 05	[illegible]21E 05	0.535E 04	0.156E 05	0.129E 05	0.353E 05	0.158E 04	0.818E 04	0.218E 05
AS-36	0.577E 05	0.824E 05	0.687E 05	0.892E 04	0.257E 05	0.209E 05	0.568E 05	0.226E 04	0.128E 05	0.364E 05
ASR-21	0.100E 05	0.148E 05	0.103E 05	0.127E 04	0.307E 04	0.325E 04	0.748E 04	0.351E 03	0.200E 04	0.611E 04
ATF-69	0.116E 04	0.159E 04	0.124E 04	0.159E 03	0.430E 03	0.390E 03	0.918E 03	0.454E 02	0.228E 03	0.735E 03
CG-16	0.175E 05	0.235E 05	0.187E 05	0.243E 04	0.541E 04	0.575E 04	0.152E 05	0.589E 03	0.347E 04	0.105E 05
CGN-38	0.509E 05	0.698E 05	0.514E 05	0.647E 04	0.162E 05	0.161E 05	0.403E 05	0.165E 04	0.983E 04	0.297E 05
CV-59	0.698E 05	0.105E 06	0.744E 05	0.903E 04	0.211E 05	0.233E 05	0.581E 05	0.244E 04	0.141E 05	0.413E 05
CV-67	0.514E 05	0.744E 05	0.615E 05	0.720E 04	0.216E 05	0.180E 05	0.444E 05	0.179E 04	0.107E 05	0.304E 05
DD-931	0.647E 04	0.903E 04	0.720E 04	0.103E 04	0.231E 04	0.224E 04	0.628E 04	0.237E 03	0.136E 04	0.396E 04
DD-963	0.162E 05	0.211E 05	0.216E 05	0.231E 04	0.137E 05	0.574E 04	0.129E 05	0.550E 03	0.336E 04	0.975E 04
DDG-2	0.161E 05	0.233E 05	0.180E 05	0.224E 04	0.574E 04	0.575E 04	0.141E 05	0.604E 03	0.338E 04	0.956E 04
DDG-37	0.403E 05	0.581E 05	0.444E 05	0.628E 04	0.129E 05	0.141E 05	0.447E 05	0.162E 04	0.912E 04	0.234E 05
FF-1037	0.165E 04	0.244E 04	0.179E 04	0.237E 03	0.550E 03	0.604E 03	0.162E 04	0.873E 02	0.388E 03	0.101E 04
FF-1052	0.983E 04	0.141E 05	0.107E 05	0.136E 04	0.336E 04	0.338E 04	0.912E 04	0.388E 03	0.219E 04	0.579E 04
LCC-19	0.297E 05	0.413E 05	0.304E 05	0.396E 04	0.975E 04	0.956E 04	0.234E 05	0.101E 04	0.579E 04	0.188E 05
LKA-113	0.942E 04	0.151E 05	0.113E 05	0.171E 04	0.307E 03	0.360E 04	0.125E 05	0.380E 03	0.254E 04	0.600E 04
LPA-248	0.886E 04	0.118E 05	0.100E 05	0.139E 04	0.381E 04	0.318E 04	0.831E 04	0.404E 03	0.195E 04	0.566E 04
LPD-4	0.110E 05	0.147E 05	0.123E 05	0.154E 04	0.466E 04	0.370E 04	0.964E 04	0.406E 03	0.229E 04	0.674E 04
LPD-12	0.162E 05	0.230E 05	0.175E 05	0.230E 04	0.587E 04	0.557E 04	0.147E 05	0.622E 03	0.348E 04	0.998E 04
LPD-13	0.150E 05	0.220E 05	0.175E 05	0.218E 04	0.598E 04	0.545E 04	0.136E 05	0.606E 03	0.325E 04	0.924E 04
LPH-2	0.851E 04	0.122E 05	0.865E 04	0.108E 04	0.279E 04	0.268E 04	0.671E 04	0.272E 03	0.163E 04	0.499E 04
LST-1179	0.800E 04	0.107E 05	0.102E 05	0.129E 04	0.422E 04	0.307E 04	0.841E 04	0.367E 03	0.181E 04	0.502E 04
SSN-637	0.143E 05	0.173E 05	0.185E 05	0.232E 04	0.112E 05	0.527E 04	0.135E 05	0.660E 03	0.341E 04	0.920E 04

Figure 14. Master Covariance Table (Weekdays)

COVARIANCE MATRIX FOR WEEKDAYS WAS AS FOLLOWS

	LKA-113	LPA-248	LPD-4	LPD-12	LPD-13	LPH-2	LST-1179	SSN-637
AD-14	0.545E 04	0.510E 04	0.562E 04	0.820E 04	0.824E 04	0.407E 04	0.465E 04	0.860E 04
AD-37	0.807E 04	0.616E 04	0.776E 04	0.113E 05	0.115E 05	0.699E 04	0.515E 04	0.922E 04
AFS-1	0.691E 04	0.415E 04	0.484E 04	0.725E 04	0.706E 04	0.363E 04	0.384E 04	0.695E 04
AO-143	0.158E 04	0.960E 03	0.113E 04	0.172E 04	0.167E 04	0.902E 03	0.854E 03	0.142E 04
AOR-1	0.262E 03	0.978E 03	0.106E 04	0.146E 04	0.185E 04	0.392E 03	0.130E 04	0.266E 04
AR-5	0.112E 05	0.829E 04	0.902E 04	0.134E 05	0.133E 05	0.587E 04	0.850E 04	0.162E 05
AS-36	0.140E 05	0.131E 05	0.149E 05	0.218E 05	0.211E 05	0.961E 04	0.133E 05	0.243E 05
ASR-21	0.167E 04	0.182E 04	0.212E 04	0.331E 04	0.310E 04	0.186E 04	0.131E 04	0.281E 04
ATF-69	0.211E 03	0.260E 03	0.279E 03	0.396E 03	0.392E 03	0.202E 03	0.219E 03	0.457E 03
CG-16	0.286E 04	0.350E 04	0.415E 04	0.581E 04	0.552E 04	0.284E 04	0.319E 04	0.560E 04
CGN-38	0.942E 04	0.886E 04	0.110E 05	0.162E 05	0.150E 05	0.851E 04	0.800E 04	0.143E 05
CV-59	0.151E 05	0.118E 05	0.147E 05	0.230E 05	0.220E 05	0.122E 05	0.107E 05	0.173E 05
CV-67	0.113E 05	0.100E 05	0.123E 05	0.175E 05	0.175E 05	0.865E 04	0.102E 05	0.185E 05
DD-931	0.171E 04	0.139E 04	0.154E 04	0.230E 04	0.218E 04	0.108E 04	0.129E 04	0.232E 04
DD-963	0.307E 03	0.381E 04	0.466E 04	0.587E 04	0.598E 04	0.279E 04	0.422E 04	0.112E 05
DDG-2	0.360E 04	0.318E 04	0.370E 04	0.557E 04	0.545E 04	0.268E 04	0.307E 04	0.527E 04
DDG-37	0.125E 05	0.831E 04	0.964E 04	0.147E 05	0.136E 05	0.671E 04	0.841E 04	0.135E 05
FF-1037	0.380E 03	0.404E 03	0.406E 03	0.622E 03	0.606E 03	0.272E 03	0.367E 03	0.660E 03
FF-1052	0.254E 04	0.195E 04	0.229E 04	0.348E 04	0.325E 04	0.163E 04	0.181E 04	0.341E 04
LCC-19	0.600E 04	0.566E 04	0.674E 04	0.998E 04	0.924E 04	0.499E 04	0.502E 04	0.920E 04
LKA-113	0.625E 05	0.207E 04	0.234E 04	0.366E 04	0.448E 04	0.141E 04	0.325E 04	0.557E 04
LPA-248	0.207E 04	0.243E 04	0.243E 04	0.341E 04	0.326E 04	0.148E 04	0.208E 04	0.440E 04
LPD-4	0.234E 04	0.243E 04	0.293E 04	0.395E 04	0.365E 04	0.176E 04	0.231E 04	0.468E 04
LPD-12	0.366E 04	0.341E 04	0.395E 04	0.594E 04	0.539E 04	0.271E 04	0.308E 04	0.587E 04
LPD-13	0.448E 04	0.326E 04	0.365E 04	0.539E 04	0.549E 04	0.252E 04	0.325E 04	0.577E 04
LPH-2	0.141E 04	0.148E 04	0.176E 04	0.271E 04	0.252E 04	0.165E 04	0.104E 04	0.225E 04
LST-1179	0.325E 04	0.208E 04	0.231E 04	0.308E 04	0.325E 04	0.104E 04	0.289E 04	0.456E 04
SSN-637	0.557E 04	0.440E 04	0.468E 04	0.587E 04	0.577E 04	0.225E 04	0.456E 04	0.150E 05

Figure 14. Master Covariance Table
(Weekdays)

The Master Covariance Table is unique because it provides a visual and easily accessible representation of the variation in KVA utilization of any particular class mix of ships.

Take for example a group of ships made up of S_2, S_4, S_5, and S_m. The value of the ensemble variance would equal the sum of the corresponding variance and covariance terms taken from the Master Covariance Table. Figure 15 exhibits this example.

	S_1	S_2	S_3	S_4	S_5 ...	S_m ...	S_n
S_1							
S_2		$V_{2,2}$		$COV_{2,4}$	$COV_{2,5}$	$COV_{2,m}$	
S_3							
S_4		$COV_{4,2}$		$V_{4,4}$	$COV_{4,5}$	$COV_{4,m}$	
S_5		$COV_{5,2}$		$COV_{5,4}$	$V_{5,5}$	$COV_{5,m}$	
⋮ S_m		$COV_{m,2}$		$COV_{m,4}$	$COV_{m,5}$	$V_{m,m}$	
⋮							
S_n							

Figure 15. Use of Master Covariance Table

Ensemble Variance would then equal $V_{2,2} + V_{4,4} + V_{5,5} + V_{m,m} + 2\ COV_{2,4} + 2\ COV_{2,5} + 2\ COV_{2,m} + 2\ COV_{4,5} + 2\ COV_{4,m} + 2\ COV_{5,m}$ which is greater than $V_{2,2} + V_{4,4} + V_{5,5} + V_{m,m} + V_{n,n}$.

6.3 Correlation Coefficient

If the correlation between the pairs of ships analyzed were zero then by definition (see Equation 12) there would not be a covariance term in the quadradic equation defining the sum of the variances (see Equation 9). The absence of covariance would permit the summation of the individual variances in defining the shape of the distribution curve. Section IV showed that there is in fact correlation between ship's time of resource usage and thus the contribution of the covariance term to the shape of the distribution is important. Figure 11 presents a representation of how the maximum demand can be influenced by the incorporation of covariance.

6.4 Determination of Variations

The major portion of the PSRPM work was in the identification and determination of the variances in KVA utilization that occurred between ships at cold iron. The data sheets which were constructed for the survey, see Figure 7a and 7b, permitted the calculation of the hourly and daily means and variances. Figure 16 is presented as an aid in the discussion of the determination of the total variance in a ship's power utilization.

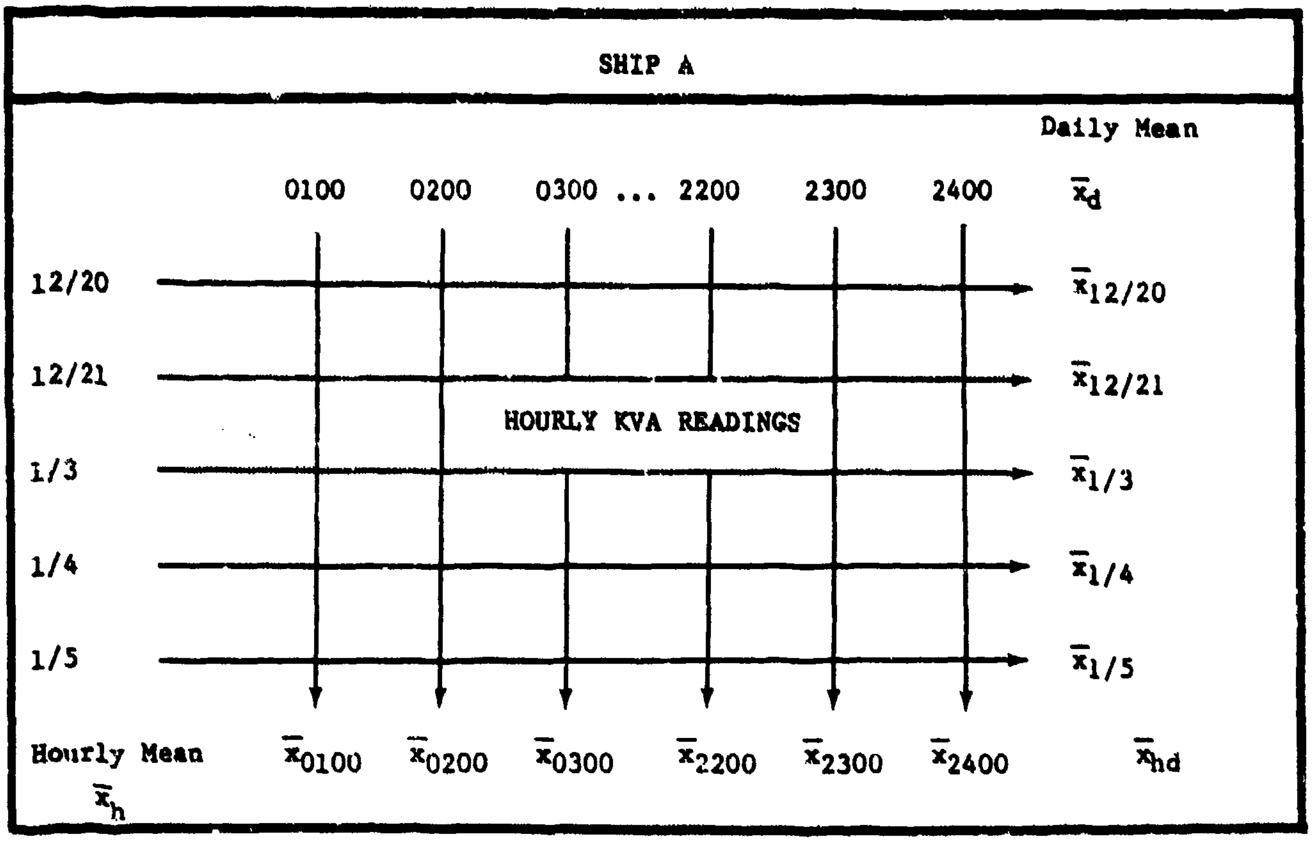

Figure 16. Notional Sewell's Point Data Sheet

From the hourly means, $\bar{x}_h$, a mean, $\bar{x}_{hd}$ and a variance s^2_h, can be calculated which represents the distribution of the power utilization over the period of one day. The daily means, $\bar{x}_d$, produce a mean, $\bar{x}_{hd}$ which is the same as the mean of the hourly means, $\bar{x}_h$, (see Section 4.2.1). But the variance that is associated with the daily means, s^2_d, is not equivalent to S^2_h. It is at this point where an indepth look at the variances is warranted.

A simplistic approach to the development of the methodology would be to neglect any correlation between the ships' power utilization and calculate the mean and sum the standard deviations for each ship class. These two statistics would define the KVA utilization distributions for the various classes of ships. An assumption of a zero correlation would result in the values of the off diagonal elements of the covariance table being zero. Thus the total variance of the distribution would result from the sum of the diagonal elements. The value of the standard deviation in a N x N covariance table would be influenced by the factor N. This procedure however would deny to the study the influence of the operational and environmental variations.

The most conservative approach, which would maximize the influence of the operational and environmental variations, makes the assumption that there is a perfect correlation (r=1) between the power utilizations of the various ship classes. This assumption creates a value of 1 for the diagonal and off diagonal elements of the covariance table. Hence, the value of the total variance would propogate as the square of the number of ship classes analyzed. (N^2) and the standard deviation would propagate as the sum of the standard deviations. The resulting statistics which define the utilization distributions would consist of a class mean and a standard deviation influenced by $\pm$ N. Example 4 illustrates the boundry conditions established by $0 \leq r \leq 1$.

Example 4:

N = 10 classes of ships each with:

$\bar{x}$ = 100 KVA

s^2 = 100 KVA

s = 10 KVA

With no correlation ($r = 0$) the summation of the 10 diagonal elements of the covariance table results in a total variance of:

$$10\ (100) = 1000 = s^2$$

thus

$$s = 31.6$$

With perfect ensemble correlation the summation of all the elements of the covariance table results in a total variance of:

$$s^2 = (100)\,(100)$$

thus

$$s = 100$$

Both conditions would have the same mean but different standard deviations.

6.4.1 Variations in KVA Utilization

Two factors may contribute to the variations in ship's electrical power consumption. These factors are the operational conditions of the ship and the environmental conditions present at the port. Variations in KVA utilization occurred from weekday to weekend. The operations profiles for the majority of the ships were based on a Monday to Friday work week. Noticeable reductions in the power requirements of each ship occurred on weekends primarily due to the crew not conducting routine training and maintenance operations on Saturdays and Sundays. The differences between weekday and weekend power requirements were great enough to require a segregation of the data. Only weekday data was used in the construction of covariance and correlation tables.

6.4.2 Operational Variations

Figure 17 shows the probability of incurring the maximum daily demand as a function of the time of day. It illustrates that peak usages usually occur at 1000 hours and at 1400 hours. This is most likely due to the preparation of meals, training, and the required system check outs. The correlation that occurs between classes of ships from hour-to-hour is incidental. It is an explicit relationship, strongly dictated by present managerial practices.

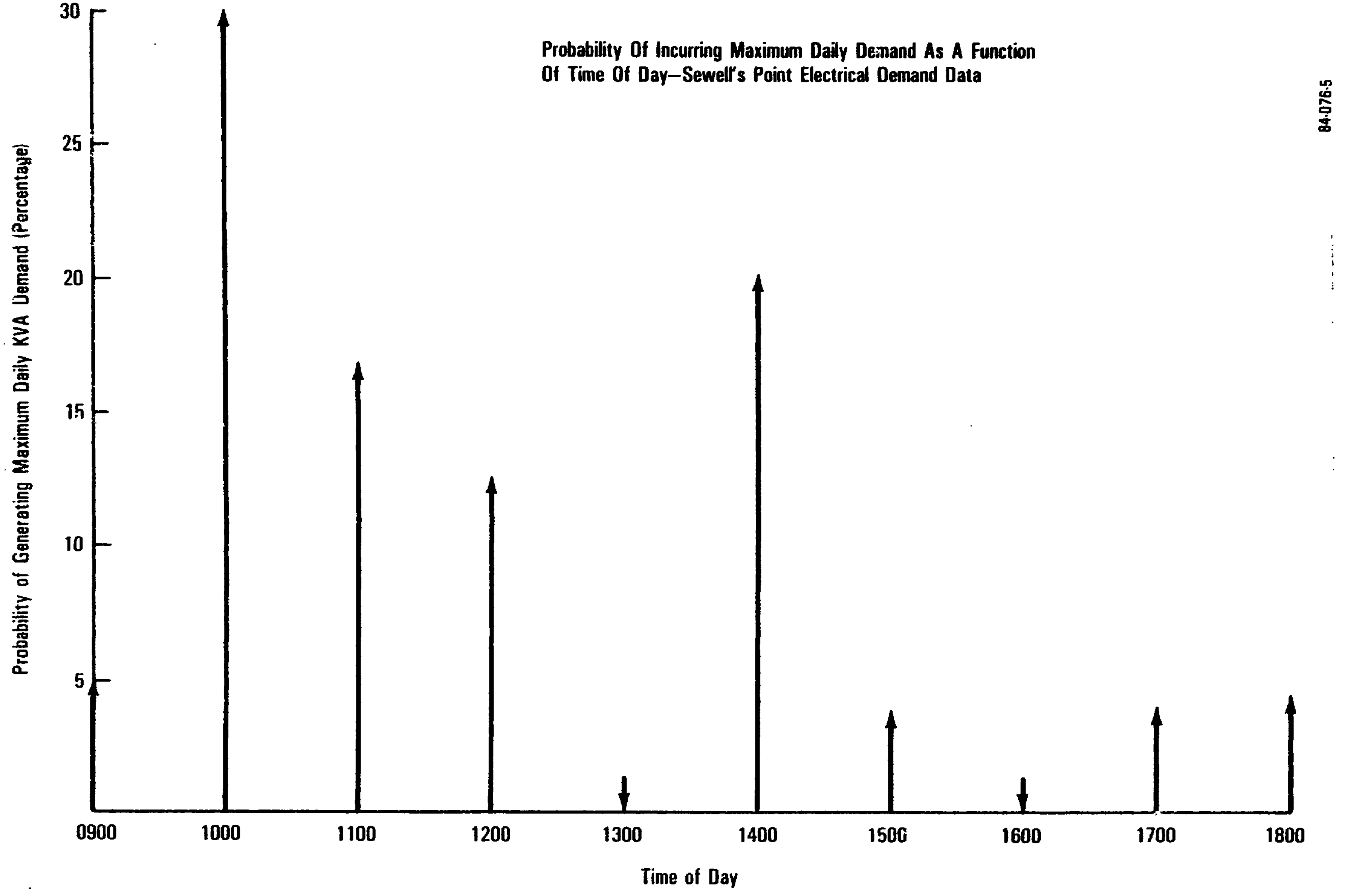

Figure 17. Maximum Daily Demand As A Function of Time of Day

6.4.3 Environmental Variations

Environmental factors such as temperature, wind speed, and cloud cover effect the power requirements of a mix of ships on a day to day basis. Changes in these conditions do not usually happen rapidly enough to be classified as time of day variations so they are considered to be day to day variations. The influence of the environment can be pictured as an addition to or subtraction from the ship's required operational loads. That is, the ships will carry out their normal day to day activities and will turn the heat up on cold days or use the air conditioner on warm days, thus increasing the total overall power utilization. The effect of the environment is the largest contributing factor to the total variance of the distribution.

6.5 Problems in the Data Sets

Hourly readings of electrical power utilization were recorded for the ships present at Sewell's Point from 20 December, 1976 to 21 January, 1977. Numerous classes of ships were present in port, but not all at the same time, and their time spent at cold iron was not necessarily continuous from day to day. Problem areas in the data sets occurred in four areas: (1) coincidentally of data, (2) discontinuity of data, (3) weekday to weekend variations, and (4) cold iron status. The only method available to cope with inconsistent or discontinuous data was for the investigator to make educated guesses on what the missing data would have been and on what effects missing data had on the final results. An elaboration on each of the problem areas is included below.

6.5.1 Coincidence of Data

Each ship maintained its individual schedule of operations and arrived and departed according to operations orders. Figure 18 shows a timeline of the presence of each ship for which data was recorded. The lack of overlapping

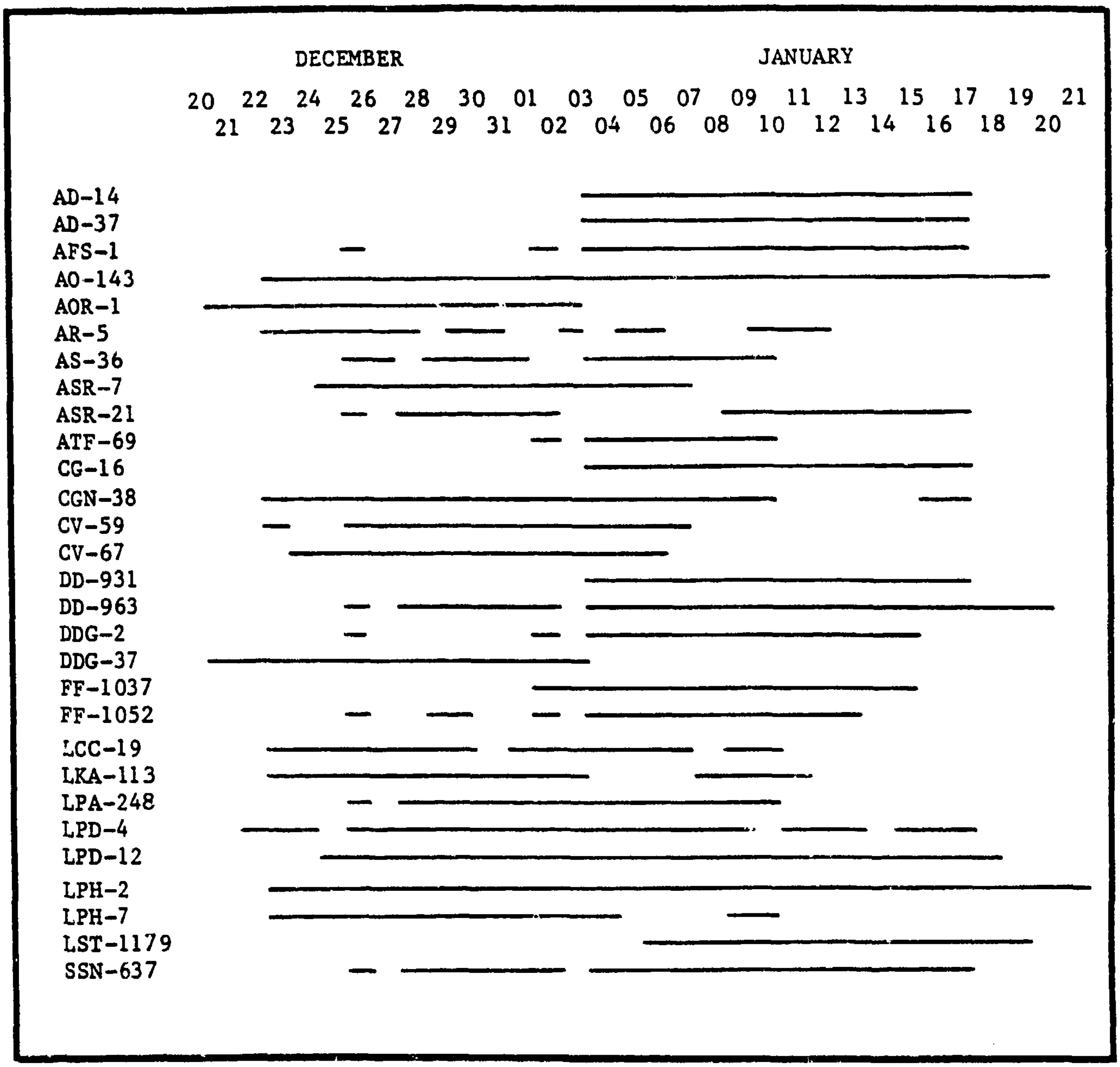

Figure 18. Timeline of Ships Present at Sewell's Point
December 20, 1976 - January 21, 1977

data prevented the complete incorporation of the day-to-day or environmental variations into the covariance table.

6.5.2 Discontinuity of Data

Interruptions in data sets occurred periodically. The two major reasons for discontinuous data sets were the failure of data recorders and the shifting of the ship's desire to use ship's power versus port power.

6.5.3 Cold Iron Status

The entire PSRPM study has assumed that if a ship was receiving power from the port than it was at cold iron. Due to the location of the electrical measuring equipment (at the transformers), it was not possible to determine if the ships drawing port supplied power were in fact at cold iron. The knowledge of whether a ship is at cold iron or not has an impact on the calculations and assumptions leading to the determination of the maximum demand. If ships are using supplied power and their probability of usage has not been taken into consideration, then the estimates arrived herein are low.

6.6 Summary

The statistics discussed in this report each had an impact on the total electrical demand of the ensemble. The mean established the central region of utilization, the correlation coefficient showed that there was more than individual variance contributing to the distribution of curve defining the power utilization, and the covariance was the contributing factor to the increase in total variance.

VII. CONCLUSIONS

7.0 Introduction

The primary output of Phase II is similar in format to that of Phase I. A graph displaying the probability that the demand for electric power will exceed capacity versus capacity was generated. Three scenarios are displayed in Figure 19. Scenario 1 is basically a Phase I/PSP1 output using the ships that were present at Sewell's Point on 22 December 1976. Scenario 2 used PSP2 and only the mean KVA utilizations as inputs and Scenario 3 included is representative of the curve if the Master Covariance Table values were incorporated into PSP2.

7.1 Objective

The object of this section is to present the conclusions reached as a result of the PSRPM Phase II.

7.2 Scenario One Sewell's Point - Using DM-25 Values

A principle output of the PSRPM is an estimate of the probability that a group of ships will exceed the electrical supply capability of the port facility. This concept was demonstrated in Phase I using Present Demand specifications stated in DM-25. In Scenario One PSP1 was run using the ships that were present at Sewell's Point on 22 December 1976 as a data base and their respective DM-25 values as KVA utilizations. The distributions created by the realizations involving the 22 December ships is represented in Figure 19 as dots.

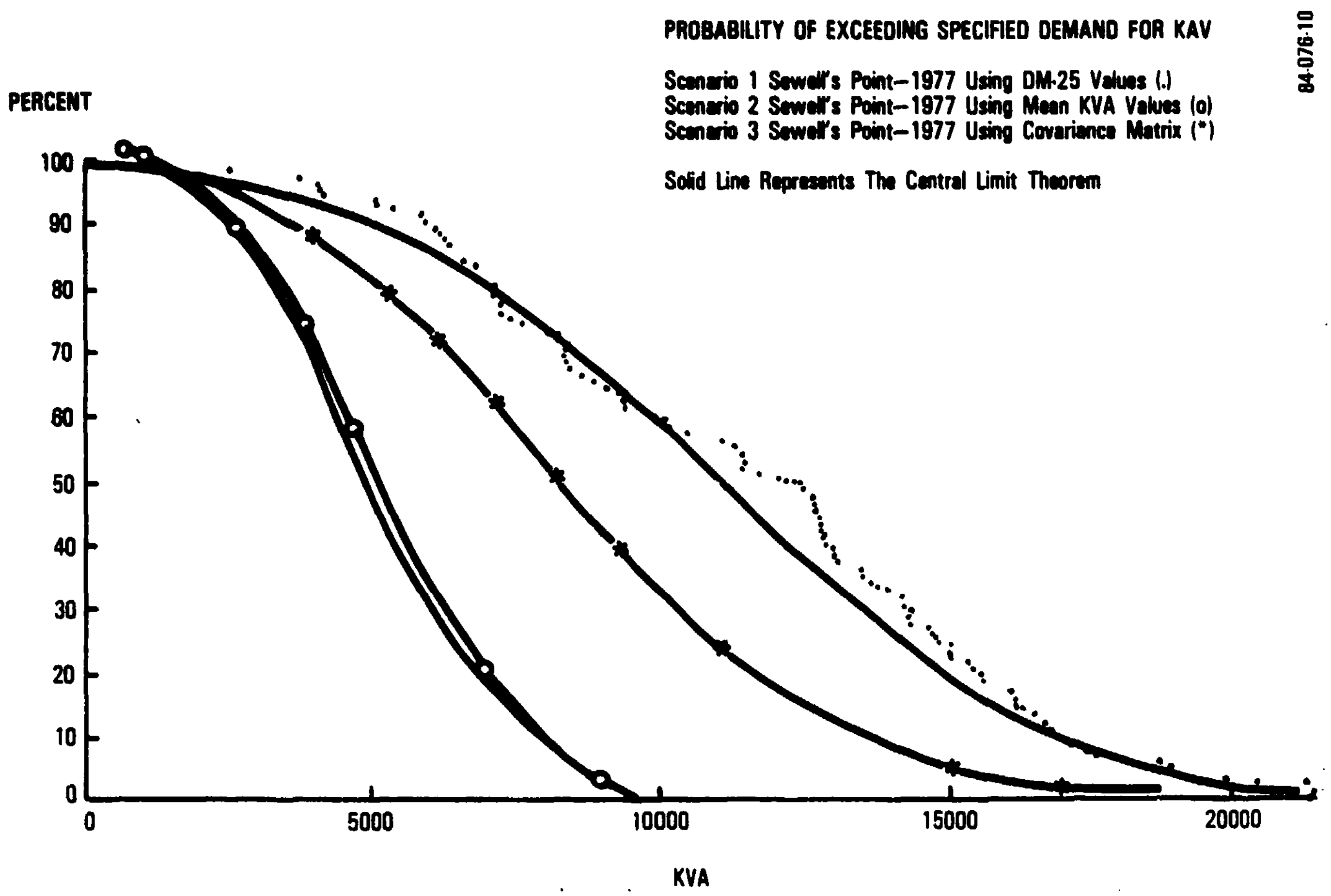

Figure 19. Probability of Exceeding Specified Demand for KVA.

7.3 Scenario Two Sewell's Point - Using Mean KVA Values

A second set of values were calculated and plotted which reflect the ships' utilization of the calculated mean KVAs. The mean values for each ship class were calculated over the surveyed time period. Phase II generated a series of random numbers to determine the number of ships present in each class per realization in accordance with the Binomial Theorem. Next, the mean KVA values corresponding to each ship class were multiplied by the number of ships in that class present in the realization and summed. Like PSP1, PSP2 executed 100 realizations and listed the total KVA values in decending order. The results of their distribution and the values corresponding to the Central Limit Theorem are plotted in Figure 19 as circles (o) and a solid line respectively.

7.4 Scenario Three Sewell's Point Using Covariance Table Values

The third curve on the graph represents what the probability of failure to meet demand curve would look like if all of the factors contributing to variation were incorporated into the covariance values. Since the variations due to the environment were not included the curve was shifted slightly to the right from where it would actually be located. This compensates for not incorporating this variance in the model. PSP2 generated a series of random numbers to determine how many ships of each class are to be present in each realization. To determine the KVA demand of the ships present, PSP2 is formatted to initiate a slightly more advanced procedure based on the distributions created by each ship's mean and the single total variance which was derived through the summation of the elements in the covariance table which are particular to that realization. If, in the process of constructing a realization, there was not a Sewell's Point calculated covariance available PSP2 substituted representative statistical values for the covariance. These representative values were determined by using a mean equal to 60% of the DM-25 value and a standard deviation of 6% of the DM-25 value in the computation of the covariance. A correlation coefficient of .8 was used as the final term in the calculation of the representative covariance. These particular values for x, s, and r were determined through analysis and comparison of the Sewell's Point data to DM-25 values. These points on the cumulative distribution curve are plotted as (*) in Figure 19.

7.5 Interpretation of Scenario Curves

Each scenario curve can be analyzed separately to reveal particular characteristics of demand specification versus probability. Or all three of the curves can be analyzed as a whole to present a picture of how the PSRPM predicted values compare to the DM-25 predicted values, and how the addition of covariance changes the shape of the curves, particularly in the distribution wing.

7.5.1 PSP2 Mean Curve Compared to PSP2 DM-25 Curve

It has always been surmised that DM-25 over estimates a port's electrical power requirements. But the safety margin built into DM-25 associated with this over designing has never been determined. Figure 20 presents KVA values of the PSP2 Mean Curve and the PSP2 DM-25 curve for constant probabilities of failure to meet demand. From these values it appears as though the DM-25 process incorporates a safety factor of approximately 2.

7.5.2 PSP2 Mean Curve Compared to PSP2 Covariance Included Curve

The PSP2 Mean Curve compared to the PSP2 Covariance Included curve shows the influance of the operational variances only. As stated before, the environmental variations were not incorporable because of non-coincident data. The slight difference in the mean hourly KVA utilizations from weekdays to

Acceptable Failure to Meet Demand Rate	PSRPM KVA Requirement	DM-25 KVA Requirement	Safety Factor
0	9700	21700	2.23
.1	8500	17500	2.06
.2	7200	15000	2.08
.4	6000	12600	2.10
.6	4700	11500	2.45
.8	3600	7500	2.08

Figure 20. Determination of Safety Factor

weekends (7.3% greater on weekdays for AOR (38 KVA), and 1.25% greater on weekdays for CGN (21 KVA) reveal that as majority of the power utilized is in fact used for environmental and hotel purposes. As stated in Section 7.4 the Covariance Included Curve was shifted slightly to the right to compensate the study for not incorporating the daily environmental variations. This shift was justified since the output of the Master Correlation Table shows that there is a very high correlation between most of the classes of ships even without considering the environmental variations. Keeping this in mind, the Scenario 3 curve tends to approach the maximum standard deviation boundary condition, r=1.

Studies and surveys to date have been mainly concerned with the mean power consumed by each single ship in port. Periodically maximum demands were recorded but no correlation to the time of the occurrance of the maximum demands has been made. The PSRPM has tried to "statistically blend" the means and variances, into a distribution which is different from a distribution based solely on the mean utilizations. The resulting widening of the wing redefines the maximum power specifications of a port given a particular mix of ships.

7.6 PSRPM Versus DM-25

Even though the PSRPM process provides an accurate prediction capability , it is a complex procedure to use. Additionally, it makes no allowance for the increase in demand that occurs in the life span of a typical Navy ship. PSRPM is useful and economical when an estimate of actual utilization would meet the needs of the circumstances being investigated. The methodology can aggregate individual ship power usage data to predict the usage by various combinations of ships and thereby is capable of predicting power use at the pier level.

The comparison of a PSRPM prediction compared to a DM-25 prediction results in an overall reduction in the predicted power demand. Thus, a design capacity derived from DM-25 appears to be conservtive.

7.7 Limitations to the PSRPM

The PSRPM output provides a demonstration as to the potential of the statistical techniques available for port system analysis. The statistical techniques used in the development of this methodology incorporate the correlation concept which in turn allow for the computation of statistically based diversity factors and an estimation of the probability of failure to meet demand given the covariance table values. Although the data was sufficient to refine PSP1 into PSP2 the methodology is limited in several areas.

The Sewell's Point Survey measured power utilization at the transformer level. Without the supporting details of usage conditions (cold iron status, stand down time, testing of ship's systems, general overhaul, temperatures and lack of sufficient overlapping data, etc.) the data reduction is subject and limited to broad statistical interpretation. Since the data was collected over the Christmas holiday season, when many personnel were on leave and ship activity was low, the power consumption cannot be considered representative of the yearly normal. In addition, it is uncertain whether an hourly sample period provides sufficient detail to identify peak loads of short duration.

The applicability of the Binominal and Central Limit Theorems impose limitations to the study. An understanding of the operational profiles of the ships, such as the time in port as compared to deployment time is essential in the assumption of a binominal distribution. Further investigation on the influence of one ship's electrical consumption affecting another ship's consumption and on the accuracy of the assumption that if a ship is not its homeport then its presence is substituted with a similar ship at the homeport, needs to be accomplished. The Central Limit Theorem made the assumption that the data could be represented by a normal distribution. The sample distributions obtained in this study are generally closer to the normal distribution in the median region with inaccuracies in the wings.

Taking into consideration the limitations stated, and realizing that the PSRPM is the demonstration of a concept which is intuitively correct with problems to be resolved, it is concluded that the results of this methodology be considered preliminary and that their use for planning estimations be subject to this fact.

VIII. RECOMMENDATIONS

8.0 Discussion

The Port Systems Requirements Prediction Methodology was developed to demonstrate the ability to make predictions about port utility service requirements. The application of the techniques developed in the PSRPM is not limited to the electrical power resource but is applicable to every service resource the port has to deliver separately or in combination. A foundation for the future development of prediction methodologies was made through the lessons learned in the overall development of the PSRPM. Based on PSRPM, enhancements to the decision making process and to the design of future data gathering programs are envisioned in experimental design; understanding of present design methods; and economic analysis.

Phase I was the initial attempt in developing a prediction methodology. It validated the theoretical basis by comparing calculated data to the Central Limit Theorem Data. The calculated data was very clean in nature since it was composed entirely of theoretical means. The output of Phase I proved to be usable and quite understandable in its application to the objective of the study. Phase II built on the first phase by incoropratina actual measured data and introducing hourly and daily utilization variances. The calculated values once again tracked very closely with the theoretical Central Limit Theorem values. An understanding of ship correlation, covariance, and the influence of large numbers of ships on the overall outcomes of a prediction has now been developed. Phase II presents areas where improvements to both the experimental process and the application of statistics may be improved. The next logical step is the development of a more refined, accurate prediction methodology, possibly a Phase III, which would involve a validation by direct comparison of its conclusions with monitored parameters.

8.1 Objective

The objective of this section is to present recommended applications of a PSRPM based procedure.

8.2 Experimental Design

The PSRPM product was developed to incorporate the Sewell's Point data. The statistical techniques used were adapted to what information was available, and the results are a product of this adaptation. The specific area where the PSRPM has contributed to future experimental designs is in the planning of data acquisition process. Sub areas of the data acquisition process, such as when to take the data, what data to take, and how many ships should be instrumented, have all been addressed in the development of the PSRPM.

8.2.1 When to Record Data

The Sewell's Point data showed that generally, the maximum power requirements occurred in the late morning and in the early to mid afternoon. Knowing this, it does not appear necessary to record data around the clock. Instead, measurements of more frequent intervals or of a continuous nature taken during the observed peak usage periods, would display short periods of maximum power utilization. Since the Sewell's Point data was acquired in the wintertime, the complete spectrum of the ships' power requirements for heating and cooling has not been completed. It appears feasible to schedule the next data gathering exercise during the season which traditionally has the greatest influence on the base's overall power requirements. Sampling rate requirements have been reviewed and it has been determined that operationally based variations require more rapid sampling than the hourly case. Environmentally induced variations can generally be estimated and should be sampled less frequently.

8.2.2 What Data to Record

An in depth analysis of the correlation coefficients and the mean power utilizations of the various classes of ships will aid the experiment designer in developing a more efficient scheme of ship instrumentation. However, ship level power utilization information is required. The next logical step would be to measure the utilization at the ship level, perhaps at the ship's buss, to determine if the ship was in fact at cold iron. This would permit the extrapolation of the data to all of the ships of a similar type, and hence, port scenarios can be synthesized and analyzed.

8.3 Assistance to Port Master Planners

The concept of forecasting the future can be seen to be very complex. One can only make educated guesses on technological advancements and requirements of the future. The PSRPM provides understandable and almost immediate feedback on the "what if's" of the future. Additionally, with refinement, an interactive capability is envisioned. This study can benefit the Port Systems Project by providing analytical procedures for utility demand data acquisition projects. With futher refinement, PSRPM could be used to assess the impact of selected MILCON Projects and/or serve as a basis of an acquisition strategy. Finally, as familiarity with the process is gained, procedures could be developed which would present NAVFAC and fleet planners with an analytical review of existing and planned facilities on an interactive basis.

8.3.1 Present Design Procedures - DM-25

The present process for establishing the electrical power service requirements for a port involves the blending of knowledge about a berthing plan with the DM-25 process. Until now, it was not clear to port planners how conservative DM-25 was. Results from the PSRPM show that DM-25 designs with a safety margin of approximately 2. The PSRPM can provide some insight to how large the power distribution system should be without approaching an overdesigned specification. Because of its simplicity, directness, and built in conservativeness the DM-25 procedure should remain the primary design approach.

8.3.2 Economic Analysis

Capital investment strategies for port electrical utilities, time value of money, and rate of return are all based on two questions; how much power is required in the future and for how long is this present supply level adequate? The PSRPM can provide assistance in estimating how long a particular power system can deliver the maximum load specification. Given an acceptable failure to meet demand rate and the known mix of ships a time of useful life of the present power system can be established. From this information, the most economical use of funds available can be determined.

8.3.3 Lead Time Estimation

When the decision is made to modify the port's existing facilities, the PSRPM can provide an estimate to the planners as to how long the present system can satisfactorily supply power. This information gives the port planner guidance on when to schedule the required construction projects.

8.4 Summary

The PSRPM project demonstrated that the statistical techniques developed can allow port planners to establish, with some confidence, the utility usage demanded for various combinations of ships which are expected to be served. A strong relationship between the data acquisition process and the validity of the PSRPM can be implied.

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APPENDIX A

PHASE II COMPUTER PROGRAMS

LISTINGS AND EXAMPLES

KVADB

KVADB is a FORTRAN program which creates the data base KVA.DBS. It contains the ship class, number of days in port, date, mean hourly KVA usage, and summed mean hourly KVA usage.

```
.DIR KVADB.FOR

%DRTLKE Non-existent file     KVADB.FOR

.DIR [KV\VK\5734,130] KVADB.FOR

KVADB    FOR     4  <057>    29-Dec-81     NOAF:    [5734,130]

.TY [5734,130] KVADB.FOR
      PROGRAM KVADB
      IMPLICIT INTEGER (A-Z)
      REAL FACTOR
      DIMENSION NAME2(2),D(30,25),M(2,25),S(2,25)
C-----------------------------------------------------------------
   10 TYPE 100
      READ(5,110,ERR=10) NAME
      OPEN(UNIT=6,ACCESS='SEQIN',FILE=NAME,DEVICE='DSK')
      OPEN(UNIT=7,ACCESS='APPEND',FILE='KVA.DBS',DEVICE='DSK')
      READ(6,120) NAME2,DAYS
      DO 20 I=1,2
      READ(6,130) (M(I,J),J=1,25)
   20 CONTINUE
      DO 30 I=1,DAYS
        READ(6,130) (D(I,J),J=1,25)
   30 CONTINUE
C   DETERMINE CONVERSION FACTOR
      M1=0
      IM1=0
      DO 40 J=1,DAYS
        IF (D(J,1) .EQ. -1) GOTO 40
        M1=M1+D(J,2)
        IM1=IM1+1
   40 CONTINUE
      M1=IFIX(FLOAT(M1)/FLOAT(IM1))
      FACTOR=FLOAT(M(1,2))/FLOAT(M1)
C   CONVERT AMPERES TO KVA
      DO 60 I=1,DAYS
        DO 50 J=2,25
          D(I,J)=IFIX(FLOAT(D(I,J))*FACTOR)
   50   CONTINUE
   60 CONTINUE
```

KVADB

```
C   CALCULATE STANDARD DEVIATION
       DO 90 J=2,25
         S1=0
         S2=0
         IS1=0
         IS2=0
         DO 80 I=1,DAYS
           IF (D(I,1) .LT. 0) GOTO 70
           S1=S1+(D(I,J)-M(1,J))**2
           IS1=IS1+1
           GOTO 80
 70        S2=S2+(D(I,J)-M(2,J))**2
           IS2=IS2+1
 80      CONTINUE
         S(1,J)=IFIX(SQRT(FLOAT(S1)/FLOAT(IS1-1)))
         S(2,J)=IFIX(SQRT(FLOAT(S2)/FLOAT(IS2-1)))
 90    CONTINUE
       S(1,1)=1
       S(2,1)=-1
C   WRITE OUT DATA INTO DATA BASE KVA.DBS
 100   FORMAT(' TYPE IN NAME OF FILE WHICH CONTAINS DATA')
 110   FORMAT(A5)
 120   FORMAT(2A5,I5,110X)
 130   FORMAT(25I5)
       WRITE(7,120) (NAME2(I),I=1,2),DAYS
       DO 140 I=1,2
         WRITE(7,130) (M(I,J),J=1,25)
         WRITE(7,130) (S(I,J),J=1,25)
 140   CONTINUE
       DO 150 I=1,DAYS
         WRITE(7,130) (D(I,J),J=1,25)
 150   CONTINUE
       CLOSE(UNIT=6,ACCESS='SEQIN',FILE=NAME,DEVICE='DSK')
       CLOSE(UNIT=7,ACCESS='APPEND',FILE='KVA.DBS',DEVICE='DSK')
       END
```

KVA.DBS

Listed below is a sample listing of KVA.DBS. It contains the ship class, the number of days in port and the hourly KVA values.

A = weekday means

B = weekday standard deviations

C = weekend means

D = weekend standard deviations minus signs denote weekends

```
.DIR KVA.DBS

KVA      DBS    126  <057>   15-Jan-82    NOAF:    [5734,130]

.TY KVA.DBS
     AD-14    14
 A  1   720   720   715   705   735   765   790   825   880   890   865   850   855   865   880
  820   825   855   830   775   765   745   750   730
 B  1    98    98   104    97    84    71    73    95    92   102   105   106    75   100   115
  108   102    53    75    88    96   118   116   110
 C -1   745   740   725   730   705   710   740   605   765   775   775   755   765   775   775
  850   800   785   760   770   765   770   755   735
 D -1    65    62    59   119    98   105   125   117   122   140   140   106   104   119   107
   92    67    75    80    73    76    91    68    50
  103   797   797   797   797   797   837   877   877   877   877   797   837   877   877   877
  877   837   797   797   797   797   797   797   797
  104   558   558   558   598   578   657   637   637   717   717   637   637   717   677   677
  598   598   837   837   637   657   578   578   558
  105   598   598   558   538   757   757   737   757   897   916   956   976   777   777   777
  777   857   857   877   857   857   797   857   857
  106   797   797   797   797   797   797   837   837   956   956   956   956   877   956  1036
  964  1016   924   885   757   717   637   637   677
  107   757   757   757   757   757   757   777   777   797   797   797   797   837   837   837
  817   817   857   837   797   757   717   717   677
 -108   677   677   677   677   677   677   677   677   677   677   677   677   677   677   677
  737   737   677   677   677   677   677   677   677
 -109   797   797   797   797   797   797   857   956   956   996   996   916   916   956   916
  916   837   837   757   797   797   757   757   757
  110   717   717   717   677   657   657   737   737   797   916   916   916   916   877   877
  797   797   797   797   797   797   797   797   717
  111   637   637   637   637   637   717   797   797   877   916   916   916   916   916   916
  837   797   797   645   598   558   558   558   558
  112   877   877   877   837   837   877   797   877   877   757   757   757   797   797   877
  877   877   877   877   837   837   877   877   837
  113   757   757   757   757   797   797   877   956   956   996   916   916   956  1036  1076
  956   837   956   916   837   837   837   797   797
  114   717   717   717   677   717   797   837   916  1036  1036   916   916   916   916   916
  916   837   837   837   837   837   877   837   817
```

-115	677	677	677	916	797	797	797	797	797	797	797	797	797	777	737
757	717	797	857	837	677	677	677	677							
-116	717	717	697	697	598	578	578	757	757	757	757	757	797	797	837
837	837	837	817	817	797	857	797	717							
AD-37		14													
1	1455	1450	1450	1430	1415	1430	1490	1685	1715	1775	1670	1650	1645	1700	1670
1645	1670	1680	1670	1625	1615	1610	1555	1515							
1	136	141	133	122	113	117	123	123	127	263	205	265	253	184	83
105	159	168	154	53	45	51	76	86							
-1	1455	1465	1465	1440	1445	1435	1435	1430	1475	1455	1455	1455	1470	1460	1440
1445	1445	1450	1465	1460	1460	1465	1445	1430							
-1	59	46	55	39	49	44	45	45	40	28	12	14	9	13	38
31	20	24	17	9	29	48	34	243							
103	1193	1170	1193	1178	1185	1185	1271	1396	1435	1505	1505	1482	1513	1505	1513
1731	1692	1724	1724	1700	1653	1638	1630	1568							
104	1560	1560	1560	1521	1521	1560	1474	1794	1872	2449	2106	2270	2231	2098	1747
1739	2106	2129	2067	1653	1638	1622	1622	1622							
105	1599	1560	1583	1529	1505	1513	1583	1786	1794	1966	1895	1755	1786	1802	1763
1833	1669	1731	1731	1692	1622	1622	1622	1536							
106	1536	1544	1552	1521	1536	1552	1716	1							

```
      NS=NSHIP-1
      DO 6 K=1,NS
      K1=K+1
      DO 6 L=K1,NSHIP
      COV(K,L)=COV(L,K)
    6 COVW(K,L)=COVW(L,K)
  100 FORMAT(A10,I5)
  101 FORMAT(25I5)
      RETURN
      END
      SUBROUTINE ESTIMA
C     THIS ROUTINE COMPUTES THE MEANS AND COVARIANCES
      CHARACTER*10 NAME(30)
      COMMON/VAR/COV(30,30),S(30),COVW(30,30),SW(30),IH(25,4,28),
     1NDAYS(30),SUM(30),SUMW(30),NSHIP,NAME
      SAVE/VAR/
      F=24.
      WRITE(3,101)
      DO 3 I=1,NSHIP
      SUM(I)=SUM(I)/F
    3 SUMW(I)=SUMW(I)/F
      DO 1 I=1,NSHIP
      DO 1 J=1,NSHIP
      COV(I,J)=(COV(I,J)-SUM(I)*SUM(J)*F)/(F-1.)
    1 COVW(I,J)=(COVW(I,J)-SUMW(I)*SUMW(J)*F)/(F-1.)
      DO 2 I=1,NSHIP
      IF(COV(I,I).GE.0.)S(I)=SQRT(COV(I,I))
      IF(COVW(I,I).GE.0.)SW(I)=SQRT(COVW(I,I))
      IF(COV(I,I).LT.0.)S(I)=SQRT(-COV(I,I))
      IF(COVW(I,I).LT.0.)SW(I)=SQRT(-COVW(I,I))
    2 WRITE(3,100)I,NAME(I),SUM(I),S(I),SUMW(I),SW(I)
  100 FORMAT(I4,A10,4F10.1)
  101 FORMAT(//'RESULTS FOR MEANS AND STD. DEVIATIONS FOR WEEKDAYS(WD) AN
     1D WEEKENDS(WE)',/// NO.     NAME      KVA(WD)       S.D.   KVA(WE)
     2    S.D.',/)
      RETURN
      END
      SUBROUTINE OUTCOR
C     THIS ROUTINE OUTPUTS THE COVARIANCE AND CORRELATION MATRICES
      CHARACTER*10 NAME(30)
      COMMON/VAR/COV(30,30),S(30),COVW(30,30),SW(30),IH(25,4,28),
     1NDAYS(30),SUM(30),SUMW(30),NSHIP,NAME
      SAVE/VAR/
      WRITE(2,89)NSHIP
      WRITE(3,98)
      DO 1 I=1,NSHIP
      WRITE(2,90)(COV(I,J),J=1,NSHIP)
      DO 2 J=1,NSHIP
    2 COV(I,J)=COV(I,J)/(S(I)*S(J))
    1 WRITE(3,100)(COV(I,J),J=1,NSHIP)
      WRITE(3,99)
      DO 3 I=1,NSHIP
      WRITE(2,90)(COVW(I,J),J=1,NSHIP)
      DO 4 J=1,NSHIP
    4 COVW(I,J)=COVW(I,J)/(SW(I)*SW(J))
    3 WRITE(3,100)(COVW(I,J),J=1,NSHIP)
   89 FORMAT(I4)
   90 FORMAT(30F10.3)
   98 FORMAT(//'CORRELATION MATRIX FOR WEEKDAYS WAS AS FOLLOWS',/)
   99 FORMAT(//'CORRELATION MATRIX FOR WEEKENDS WAS AS FOLLOWS',/)
  100 FORMAT(25F5.2)
      RETURN
      END
```

```
C     THIS PROGRAM DETERMINES THE COVARIANCE MATRIX AND THE CORRELATION
C     MATRIX FOR THE SEWELL'S POINT HOURLY AVERAGES DATA.
      CHARACTER*10 NAME(30)
      COMMON/VAR/COV(30,30),S(30),COVW(30,30),SW(30),IH(25,4,28),
     1NDAYS(30),SUM(30),SUMW(30),NSHIP,NAME
      SAVE/VAR/
      OPEN(UNIT=4,FILE='KVA.DAT',STATUS='OLD')
      OPEN(UNIT=3,FILE='TEMP.OUT',STATUS='NEW')
      OPEN(UNIT=2,FILE='CORR.OUT',STATUS='NEW')
      CALL INIT
      CALL INPUT
      CALL ESTIMA
      CALL OUTCOR
      CLOSE(UNIT=2)
      CLOSE(UNIT=3)
      CLOSE(UNIT=4)
      STOP
      END
      SUBROUTINE INIT
C     THIS ROUTINE ZEROES OUT THE REQUIRED SAMPLING ARRAYS
      CHARACTER*10 NAME(30)
      COMMON/VAR/COV(30,30),S(30),COVW(30,30),SW(30),IH(25,4,28),
     1NDAYS(30),SUM(30),SUMW(30),NSHIP,NAME
      SAVE/VAR/
      DO 1 I=1,30
      SUM(I)=0.
      SUMW(I)=0.
      DO 1 J=1,30
      COV(I,J)=0.
    1 COVW(I,J)=0.
      RETURN
      END
      SUBROUTINE INPUT
C     THIS ROUTINE INPUTS AND PREPROCESSES THE SEWELL'S POINT KVA DATA
      CHARACTER*10 NAME(30)
      COMMON/VAR/COV(30,30),S(30),COVW(30,30),SW(30),IH(25,4,28),
     1NDAYS(30),SUM(30),SUMW(30),NSHIP,NAME
      SAVE/VAR/
      I=1
    1 READ(4,100,END=2)NAME(I),NDAYS(I)
      SS=0.
      SSW=0.
      WRITE(3,100)NAME(I),NDAYS(I)
      N=NDAYS(I)
      READ(4,101)((IH(J,K,I),J=1,25),K=1,4)
      WRITE(3,101)((IH(J,K,I),J=1,25),K=1,4)
      DO 4 K=1,24
      SUM(I)=SUM(I)+IH(K+1,1,I)
      SUMW(I)=SUMW(I)+IH(K+1,3,I)
      SS=SS+IH(K+1,2,I)**2
      [illegible]
      DO 4 L=1,I
      [illegible]
    4 COVW(I,L)=COVW(I,L)+IH(K+1,2,I)*IH(K+1,3,L)
      [illegible]
      COVW(I,I)=COVW(I,I)+SSW
      I=I+1
      DO 3 K=1,N
    3 READ(4,100)
      GO TO 1
    2 NSHIP=I-1
C     FILL OUT THE COVARIANCE MATRIX TERMS
```

PSP2.FOR

.TY PSP2.FOR

```
C     THIS PROGRAM SIMULATES PORT SERVICE DEMAND OVER A NUMBER OF TIME
C     PERIODS AND DETERMINES THE PROBABILITY DISTRIBUTION OF THE DEMAND
C     FOR A NUMBER OF RESOURCES.
C     READ THE INPUT
      OPEN(UNIT=5,ACCESS='SEQIN',FILE='PSP.DAT',DEVICE='DSK')
      OPEN(UNIT=8,ACCESS='APPEND',FILE='PSP2.ARC',DEVICE='DSK')
      OPEN(UNIT=6,ACCESS='SEQOUT',FILE='PSP.OUT',DEVICE='DSK')
    1 CALL DESCR
C     COMPUTE MEANS AND VARIANCES OF CLASS DEMANDS
      CALL STATS
C     COMPUTE THE CUMULATIVE PROBABILITY DISTRIBUTIONS
      CALL INIT
C     PERFORM SIMULATION
      CALL SIMUL
C     OUTPUT THE RESULTS
      CALL OUTPUT
      CLOSE(UNIT=7,ACCESS='APPEND',FILE='PSP.ARC',DEVICE='DSK')
       CLOSE(UNIT=6,ACCESS='SEQOUT',FILE='PSP.OUT',DEVICE='DSK')
```

PSP2.FOR

```
      CLOSE(UNIT=8,ACCESS='APPEND',FILE='PSP2.ARC',DEVICE='DSK')
      END
      SUBROUTINE DESCR
C     THIS ROUTINE INPUTS THE REQUIRED DATA
C      THE INPUT PARAMETERS ARE AS FOLLOW:
C        NCLASS   = NUMBER OF SHIP CLASSES SERVICED BY FACILITY
C                 = 0 TO STOP
C                 = NEGATIVE IF ONLY THE SHIP POPULATION CHANGES FROM
C                   PREVIOUS CASE RUN
C        NRS      = NUMBER OF RESOURCES OF INTEREST
C        IDUMP    = 1 FOR A DUMP OF THE INPUT (0 OTHERWISE)
C        NAMER(I)= NAME OF ITH RESOUCE
C        NAMEC(I)= NAME OF ITH SHIP CLASS
C        PR(I)    = PROBABILITY THAT MEMBER OF ITH CLASS REQUIRES SERVICE
C        R(J,I)   = AMOUNT OF JTH RESOURCE REQUIRED BY ITH SHIP CLASS
C        NSHIP(I)= TOTAL RELEVANT POPULATION IN ITH SHIP CLASS
C        NPER     = NUMBER OF REALIZATIONS TO BE GENERATED
C        NKE      = NUMBER OF HIGH DEMANDS OF EACH RESOUCE TO BE RETAINED
C        IXX      = INITIAL RANDOM NUMBER (=0 FOR STANDARD R.N. SET)
C                  MCODE  = 6 CHARACTER ID. CODE
      DIMENSION MCODE(6)
      COMMON /COV/ COVAR(50,50,1)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      OPEN(UNIT=7,ACCESS='APPEND',FILE='PSP.ARC',DEVICE='DSK')
      OPEN(UNIT=9,ACCESS='SEQIN',FILE='COVTAB.DAT',DEVICE='DSK')
 1010 FORMAT(50E12.6)
      IX=4973127
      NCL=NCLASS
      READ(5,105,END=5) MCODE
  105 FORMAT(6A1)
      WRITE(7,105) MCODE
      WRITE(8,105) MCODE
      READ(5,100)NCLASS,NRS,IDUMP
      IF(NCLASS.EQ.0)GO TO 5
      DO 1000 K=1,NCLASS
        READ(9,1010) (COVAR(J,K,1),J=1,NCLASS)
```

PSP2.FOR

```
1000 CONTINUE
     READ(5,89)MSG
     WRITE(7,89) MSG
     WRITE(8,89) MSG
     IF(NCLASS.LT.0)GO TO 3
     WRITE(7,106) NCLASS,NRS
     WRITE(8,106) NCLASS,NRS
 106 FORMAT(I3,3X,I3)
     READ(5,101)(NAMER(I),I=1,NRS)
     WRITE(7,999) (NAMER(I),I=1,NRS)
     WRITE(8,999) (NAMER(I),I=1,NRS)
 999 FORMAT(3(A4,3X))
     DO 2 I=1,NCLASS
   2 READ(5,102)NAMEC(I),PR(I),(R(J,I),J=1,NRS)
     GO TO 4
   3 NCLASS=NCL
   4 CONTINUE
     READ(5,100)(NSHIP(I),I=1,NCLASS)
     READ(5,103)NPER,NKE,IXX
     WRITE(7,107) NPER,NKE
 107 FORMAT(I6,3X,I6)
     IF(IXX.NE.0)IX=IXX
     GO TO 6
   5 CLOSE(UNIT=5,ACCESS='SEQIN',FILE='PSP.DAT',DEVICE='DSK')
     CLOSE(UNIT=7,ACCESS='APPEND',FILE='PSP.ARC',DEVICE='DSK')
     STOP
  88 FORMAT(' ENTER SENARIO DESCRIPTION IN 72 CHARACTERS OR LESS')
  89 FORMAT(18A4)
  90 FORMAT(///'0ENTER NO. OF SHIP CLASSES AND NO. OF RESOURCES(2I3)')
  91 FORMAT(' ENTER',I4,' RESOURCE NAMES (NA4)')
  92 FORMAT(' ENTER CLASS NAME, PROB. OF DEMAND AND RESOURCE DEMANDS(A4
    1,NF7.3)')
  93 FORMAT(' ',I3)
  94 FORMAT(' ENTER SHIP CLASS POPULATIONS(24I3)')
  95 FORMAT(' ENTER NO. OF SIMULATIONS,NO. KEPT,AND INITIAL R.N.(3I6)')
 100 FORMAT(24I3)
 101 FORMAT(20A4)
```

PSP2.FOR

```
  102 FORMAT(A4,10F7.3)
  103 FORMAT(3I6)
    6 RETURN
      END
      SUBROUTINE INIT
C     THIS ROUTINE INITIALIZES THE CUMULATIVE DISTRIBUTION FUNCTION
C     COMPUTED ON THE BASIS OF THE BINOMIAL DISTRIBUTION.
      COMMON/COV/ COVAR(50,50,1)
      COMMON/COMP/PROB(1000),NST(51)
      COMMON/AMERIT/BIG(2,1000),IPOS(2,1000),NKEPT,MM,REG(20)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      NST(1)=0
      DO 1 I=1,NCLASS
      NN=NSHIP(I)
      FN=NN
      NN1=NN+1
      NST(I+1)=NST(I)+NN1
      P=PR(I)
      Q=1.-P
      PQ=P/Q
      K=NST(I)+1
      PP=Q**FN
      PROB(K)=PP
      IF(NN.EQ.0)GO TO 1
      DO 1 J=1,NN
      K=K+1
      PP=PP*PQ*FLOAT(NN1-J)/FLOAT(J)
      PROB(K)=PROB(K-1)+PP
    1 CONTINUE
      NKEPT=0
      RETURN
      END
      SUBROUTINE SIMUL
C     THIS ROUTINE SIMULATES PORT SERVICE DEMAND FOR A SET OF SPECIFIED
C     RESOUCES.
      COMMON /COV/ COVAR(50,50,1)
```

PSP2.FOR

```
      DIMENSION FN(50),RMN(3),SIGMA(3)
      COMMON/COMP/PROB(1000),NST(51)
      COMMON/AMERIT/BIG(2,1000),IPOS(2,1000),NKEPT,MM,REQ(20)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      WRITE(6,100) (NAMER(I1),I1=1,NRS)
      MM=10
      DO 50 II=1,NPER
        DO 10 L=1,NRS
          REQ(L) = 0.0
   10   CONTINUE
        DO 40 J=1,NCLASS
          CALL RANDU(IX,IY,XX)
          IX = IY
          NN = NST(J)
          NM = NSHIP(J)
          DO 20 K=1,NM
            IF (XX .LT. PROB(K+NN)) GOTO 30
   20     CONTINUE
   30     FN(J) = FLOAT(K-1)
   40   CONTINUE
C    COMPUTE STANDARD DEVIATION
      DO 95 L=1,NRS
      SIGMA(L) = 0.0
      DO 70 I=1,NCLASS
        IF (I .EQ. 1) GOTO 60
        DO 60 J=1,I-1
          SIGMA(L) = SIGMA(L) + 2*COVAR(I,J,1)*FN(I)*FN(J)
   60   CONTINUE
        SIGMA(L) = SIGMA(L) + COVAR(I,I,1)*(FN(I)**2)
   70 CONTINUE
      SIGMA(L) = SQRT(SIGMA(L))
C  COMPUTE MEAN DEMAND
        RMN(L) = 0.0
        DO 80 I=1,NCLASS
          RMN(L) = RMN(L) + FN(I)*R(L,I)
   80   CONTINUE
```

PSP2.FOR

```
   95 CONTINUE
C  COMPUTE GAUSSIAN DISTRIBUTED DEMANDS
           ILOC = (II-1)*MM
           DO 88 J=1,MM
             ILOC = ILOC + 1
         DO 86 L=1,NRS
             A = 0.0
             DO 85 K=1,12
               CALL RANDU(IX,IY,Y)
               IX = IY
               A=A+Y
   85        CONTINUE
             REQ(L) = (A-6.0)*SIGMA(L) + RMN(L)
   86    CONTINUE
             CALL PLACE(ILOC)
             WRITE(6,101) ILOC,(REQ(L),L=1,NRS)
   88      CONTINUE
   50 CONTINUE
  100 FORMAT(//' SIMULATED REALIZATIONS OF RESOURCE DEMANDS'/
     1' ',5X,6(3X,A4,2X))
  101 FORMAT(' ',I4,8F9.1)
      RETURN
      END
      SUBROUTINE OUTPUT
C     THIS ROUTINE OUTPUTS THE LARGEST DEMANDS AND THEIR GENERATION NO.
      COMMON/COMP/PROB(1000),NST(51)
      COMMON/AMERIT/BIG(2,1000),IPOS(2,1000),NKEPT,MM,REQ(20)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      WRITE(6,100) NKE,(NAMER(I),I=1,NRS)
      DO 2 J=1,NRS
        WRITE(7,102) (BIG(J,I), I=1,NKE*MM,MM)
    2 CONTINUE
      DO 3 I=1,NKE*MM,MM
      WRITE(6,101) I,(BIG(J,I),IPOS(J,I),J=1,NRS)
    3 CONTINUE
  102 FORMAT(20(2X,E11.4))
```

PSP2.FOR

```
  100 FORMAT('THE LARGEST',I4,' DEMANDS FOR EACH RESOURCE WERE AS FO
     1LLOW'//' ',6(10X,A4))
  101 FORMAT(' ',I3,5(F9.1,I4))
      RETURN
      END
      SUBROUTINE PLACE(ILOC)
C     THIS ROUTINE CHECKS TO SEE IF ANY OF THE COMPUTED RESOURCE DEMANDS
C     IN THE ILOCTH REALIZATION LIE IN THE HIGHEST GROUP
      COMMON/COMP/PROB(1000),NST(51)
      COMMON/AMERIT/BIG(2,1000),IPOS(2,1000),NKEPT,MM,REQ(20)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      NTEM = NKE*MM
      IF(NKEPT.GT.NTEM)NKEPT=NTEM
      NK=NKEPT
      NK2=NK+2
      NK3=NK+3
      NKEPT=NKEPT+1
      DO 12 I=1,NRS
      J=1
      IF(NKEPT.EQ.1)GO TO 2
      IF(NKEPT.GT.NTEM.AND.REQ(I).LT.BIG(I,NK))GO TO 12
      DO 3 J=1,NK
      IF(REQ(I).LE.BIG(I,NKEPT-J))GO TO 4
    3 CONTINUE
    4 IF(J.EQ.1)GO TO 2
C     MOVE UP (J-1) VALUES AND POSITION INDICATORS
      DO 5 K=3,J
      IF(NK3-K.GT.NTEM)GO TO 5
      BIG(I,NK3-K)=BIG(I,NK2-K)
      IPOS(I,NK3-K)=IPOS(I,NK2-K)
    5 CONTINUE
C     INSERT NEW VALUES
    2 BIG(I,NK2-J)=REQ(I)
      IPOS(I,NK2-J)=ILOC
   12 CONTINUE
      RETURN
```

```
      END
      SUBROUTINE DUMP
C     THIS ROUTINE DUMPS THE INPUT DATA
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      DATA LAB/'PROB'/
      WRITE(6,99) MSG
      WRITE(6,100)NCLASS,NRS,NPER,NKE,IX,(NAMER(I),I=1,NRS),LAB
      DO 1 I=1,NCLASS
      WRITE(6,101) NAMEC(I),(R(J,I),J=1,NRS),PR(I)
    1 WRITE(6,102) NSHIP(I)
   99 FORMAT(18A4)
  100 FORMAT('NUMBER OF CLASSES=',I4,6X,'NUMBER OF RESOURCES=',
     1I4/'NUMBER OF REALIZATIONS REQUESTED=',I5/'NUMBER KEPT='
     2,I4/'INITIAL RANDOM NUMBER=',I10/
     3' RESOURCE DEMAND MATRIX IS AS FOLLOWS:'//' ',3X,6(6X,A4))
  101 FORMAT(A4,5F10.3)
  102 FORMAT(65X,I5)
      RETURN
      END
      SUBROUTINE STATS
C     THIS SUBROUTINE COMPUTES MEANS AND VARIANCES OF RESOURCE
C     REQUIREMENTS OF THE CLASSES AND COMPUTES THE PERCENTILES
C     OF THE TOTAL RESOURCE USE BY THE CENTRAL LIMIT THEOREM.
      COMMON /COV/ COVAR(50,50,1)
      COMMON/DATA/NCLASS,NRS,NPER,NKE,IX,NAMER(20),NSHIP(50),PR(50),
     1NAMEC(50),R(20,50),IDUMP,MSG(18)
      DIMENSION OUT(20,2),SUM(20),VAR(20),PERC(23),PMULT(23),ANS(50)
      DATA PERC/99.,98.,97.,96.,95.,90.,95.,80.,75.,70.,60.,50.,
     140.,30.,25.,20.,15.,10.,5.,4.,3.,2.,1./
      DATA PMULT/-2.327,-2.054,-1.881,-1.751,-1.645,-1.382,-1.037,
     1-0.842,-0.674,-0.524,-0.253,0.0,0.253,0.524,0.674,0.842,1.037,
     21.382,1.645,1.751,1.881,2.054,2.327/
      DATA NPERC/23/
      WRITE(6,99) MSG
      WRITE(6,100) (NAMER(J),J=1,NRS)
      DO 1 J=1,NRS
      SUM(J)=0.
    1 VAR(J)=0.
      DO 10 J=1,NCLASS
```

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```
         ANS(J) = FLOAT(NSHIP(J))*PR(J)
   10  CONTINUE
       DO 3 I=1,NCLASS
       FN=ANS(I)*(1.-PR(I))
       DO 2 J=1,NRS
       OUT(J,1)=R(J,I)*ANS(I)
       V=R(J,I)**2*FN
       OUT(J,2)=SQRT(V)
       SUM(J)=SUM(J)+OUT(J,1)
       IF (I .EQ. 1) GOTO 20
       DO 20 K=1,I-1
         VAR(J) = VAR(J) + 2*ANS(K)*ANS(I)*COVAR(K,I,J)
   20  CONTINUE
       VAR(J) = VAR(J)+COVAR(I,I,J)*ANS(I)**2+V
       TYPE 9999, I,ANS(I),COVAR(I,I,J)
 9999  FORMAT(I5,2X,F6.2,3X,E11.4)
    2  CONTINUE
       WRITE(6,101) NAMEC(I),(OUT(J,1),J=1,NRS)
       WRITE(6,102) (OUT(J,2),J=1,NRS)
       WRITE(8,109) (OUT(J,1),OUT(J,2),J=1,NRS)
  109  FORMAT(6(2X,F10.3))
    3  CONTINUE
       DO 4 J=1,NRS
    4  VAR(J)=SQRT(VAR(J))
   99  FORMAT(//' ',18A4/' MEANS AND STANDARD DEVIATIONS OF RESOURCE DEMA
      1NDS')
  100  FORMAT(' ',4X,6(10X,A4))
  101  FORMAT(' ',A4,6(4X,F10.3))
  102  FORMAT(' ',2X,6('  ',F10.3))
  103  FORMAT('0ALL',6(4X,F10.3))
  105  FORMAT(' ',F6.1,4X,6(F10.3,4X))
       DO 5 I=1,NPERC
       DO 6 J=1,NRS
    6  OUT(J,1)=SUM(J)+PMULT(I)*VAR(J)
       WRITE(7,96) (OUT(J,1),J=1,NRS)
    5  CONTINUE
   96  FORMAT(20(2X,E11.4))
       RETURN
       END
```