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MARINE INDUSTRY STANDARDS  
WELDING  
INDUSTRIAL ENGINEERING  
EDUCATION AND TRAINING**

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The Use of Statistical Methods in Di-  
mensional Process Control**

**U.S. DEPARTMENT OF THE NAVY  
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# Report Documentation Page

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THE USE OF STATISTICAL METHODS IN  
DIMENSIONAL PROCESS CONTROL

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THE USE OF STATISTICAL METHODS IN

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ABSTRACT

In shipbuilding, the stage of construction which lends itself to the most time and cost reduction is unit erection in the basin or on the ways. This requires all units to be complete and accurately assembled in order to eliminate costly rework during and after erection. To achieve this high degree of unit accuracy, we have begun a pilot dimensional control program that has set the guidelines for systematically monitoring each stage of the production process prior to erection. Through the collection and analysis of data, we can take steps to control each process and insure that we are achieving our desired degree of accuracy. The cumulative effects of "fine tuning" each individual work process will ultimately lead to improvement in the dimensional accuracy of our completed units.

This paper discusses our experience in applying statistical methods in the collection and interpretation of dimensional data on our automatic burning machines. The results obtained and the benefits derived from the pilot program have proved to us that statistical process control, as applied successfully in Japanese shipyards, is a viable method for improving productivity in the shipbuilding industry.

## PROGRAM OVERVIEW

The three basic concepts that form the foundation for our pilot program are:

- \* The application of process lanes.
- \* The establishment of process standards.
- \* The development of a statistical database.

### 1. The application of process lanes.

A process lane is simply the categorization and separation of like kinds of work (1). From a dimensional control viewpoint, a process lane provides repeatable processes. If a process is repeatable, statistics can be used to analyze observed variations from normal performance. Exhibit 1 illustrates the categories of assemblies and separation of work areas that make up our process lanes (2).

### 2. The establishment of process standards.

For the purposes of our pilot program, we have defined a Process Control Standard as:

A mutually agreed upon, formally published description of a work process for the purpose of defining certain characteristics of that work process that must be the same (within a specified tolerance) each time the work process is performed (3).

PROCESS LANE CATEGORIZATION

A. MAIN ASSEMBLY

CATEGORIES

- Category 1 - Flat Panel Units
- 2 - Curved Shell Units
- 3 - Superstructure Units
- 4 - Fore and Aft Peak Units
- 5 - Engine Rm. Doublebottom Units
- 6 - Special Weldments

ASSEMBLY AREAS

- Panel Shop
- 11, 12, 13, 14 Tables
- 13, 14 Tables, Dk. House Jig
- 12, 13, 14 Tables (Jigs)
- Panel Shop/12, 13, 14 Tables
- Various

B. SUB-ASSEMBLY

CATEGORIES

- Category 1 - Floors
- 2 - Girders, Webs
- 3 - Longitudinal Bhds.
- 4 - Transverse Bhds.
- 5 - Built-up Beams
- 6 - Brackets
- 7 - Bhds. (not produced in panel line)
- 8 - Special Weldments

ASSEMBLY AREAS

- 21, 22, 23, 24 Tables
- Various

C. FABRICATION

CATEGORIES

- Category 1 - Shell Plates
  - A. Straight Line Cut
  - B. Irregular Shape
    - 1. Roll
    - 2. Roll & Line Heat
    - 3. Press
    - 4. Roll & Blacksmith
- 2 - Internal Members
  - A. Main Plate
    - 1. Roll
    - 2. Roll & Line Heat
    - 3. Press
    - 4. Roll & Blacksmith
- 3 - Structural Members
  - A. Purchased Shapes
    - 1. Straight
    - 2. Curved
  - B. Built-up Stiffeners
    - 1. Straight
    - 2. Curved
  - C. Angle Cut from Channels
    - 1. Straight
    - 2. Curved
  - D. Flat Bars
    - 1. Straight
    - 2. Curved

FABRICATION AREAS

- Exactograph
- #2 A.B.M.
- Rolls
- Rolls/Furnace Area
- Press
- Rolls/Furnace Area
  
- #3 & #4 A.B.M.
- Rolls
- Rolls/Furnace Area
- Press
- Rolls/Furnace Area
  
- Shape Layout Area
- Frame Bender/Furnace Area
  
- Fab Shop
- Frame Bender/Furnace Area
  
- Shape Travograph
- Frame Bender & Travo
  
- Plate Travograph
- Frame Bender/Furnace Area

Standard ranges and tolerances were set for each work process after careful consideration of vital dimensions, common shipbuilding practice, and classification society requirements for the finished vessel.

Our process standards will **be** reviewed and/or revised on a regular basis. They must reflect changes in work processes due to refinements in methods or equipment, changes in the nature of the work being performed at a given time, and changes in owner or classification society requirements. Exhibit 2 illustrates a process control standard for parts fabrication on our No. 3 Automatic Burning Machine (No. 3 ABM).

### 3. The development of a statistical database.

A statistical database is a quantitative measure of normal work performance at each work station. Once a database is established, it will serve as a permanent record of the process capabilities. Refinements to any process through changes in procedures or equipment can be measured by direct comparison of new performance vs. the database. Also, the compilation of database variables (mean, variance, standard deviation) is a prerequisite for the use of variation merging equations to predict excess and shrinkage allowances for each assembly.



## PROGRAM RESULTS

The pilot program consisted of monitoring the performance of two burning machines: The No. 3 ABM, a Linde Model CM-100 n/c plasma arc machine, and the Inside Travograph, a 4 torch optically controlled oxy-fuel machine. The No. 3 ABM was scheduled for extensive overhaul (replacement of drive mechanism from "pinch type" roller to rack & pinion, and replacement of main control console). The Inside Travograph was scheduled to be scrapped and replaced with a new Linde Model CM-100, 12 torch n/c oxy-fuel machine.

The objective of the program was to establish a statistical history of the machines' capabilities prior to the scheduled maintenance project, and provide evidence that the upgraded machines operate within the accuracy limits of our process standards and the machines' purchase specifications.

### 1. Regular (Daily) Analysis.

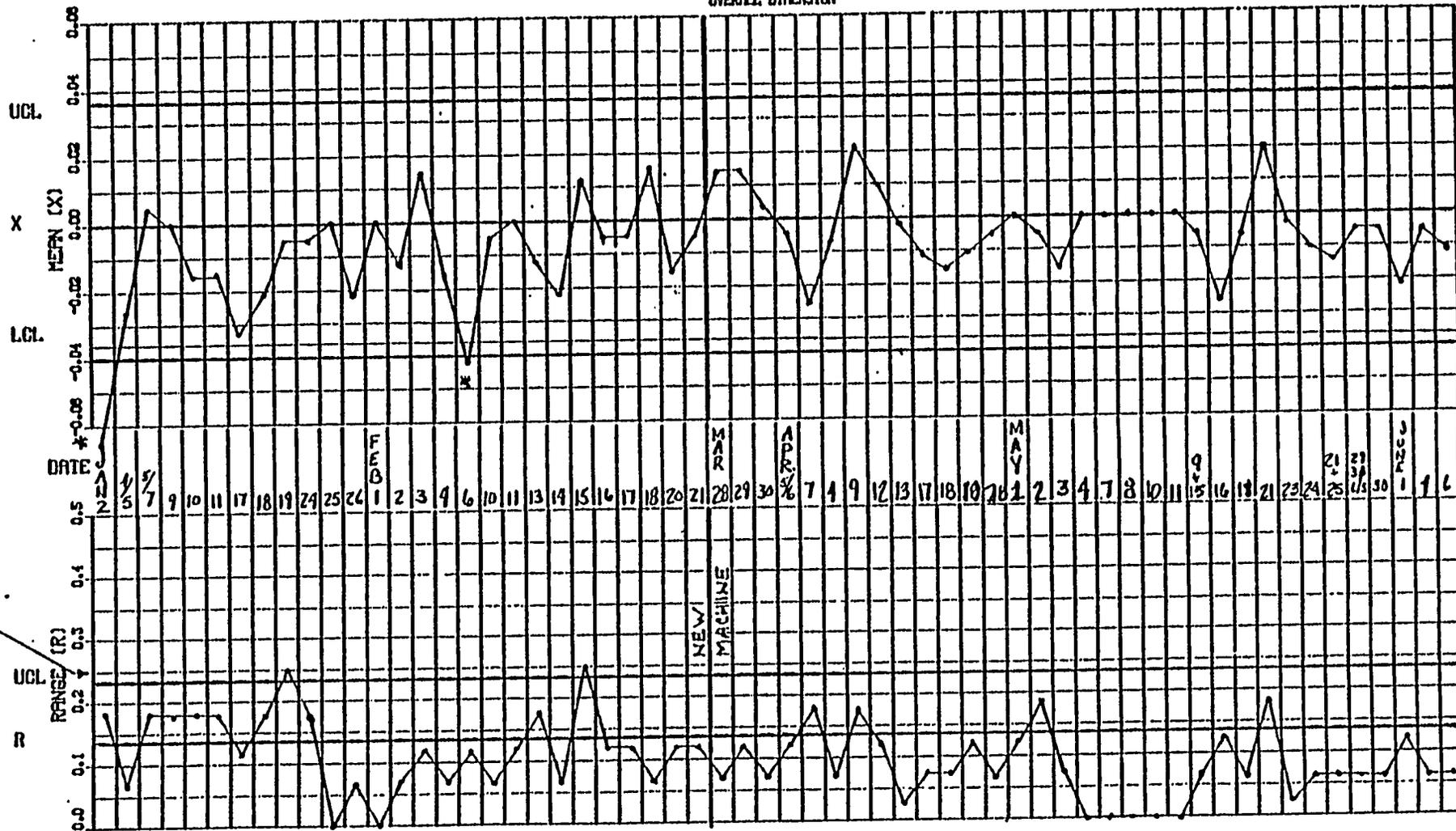
Control of each machine was achieved through the daily collection and evaluation of dimensional data. Machine operators performed daily dimensional checks which were recorded on dimensional control worksheets and used to construct (X,R) control charts (Exhibit 3).

The upper and lower control limits were set to coincide with the values of our process control standards. For example, the limits for overall dimensions of burned pieces (Exhibit 3) represent a 99% probability that the machine is burning within the tolerance limits of  $0+1/8$  inch.

ACCURACY CONTROL CHART  
 NO 3 ARM FIRST SHIFT  
 FAB SHOP SAMPLE SIZE - 12  
 OVERALL DIMENSION

X BAR CHART  
 $\bar{X}$  - 0.0  
 UCL - 0.0361  
 LCL - -0.0361

R CHART  
 $\bar{R}$  - 0.1358  
 UCL - 0.2331



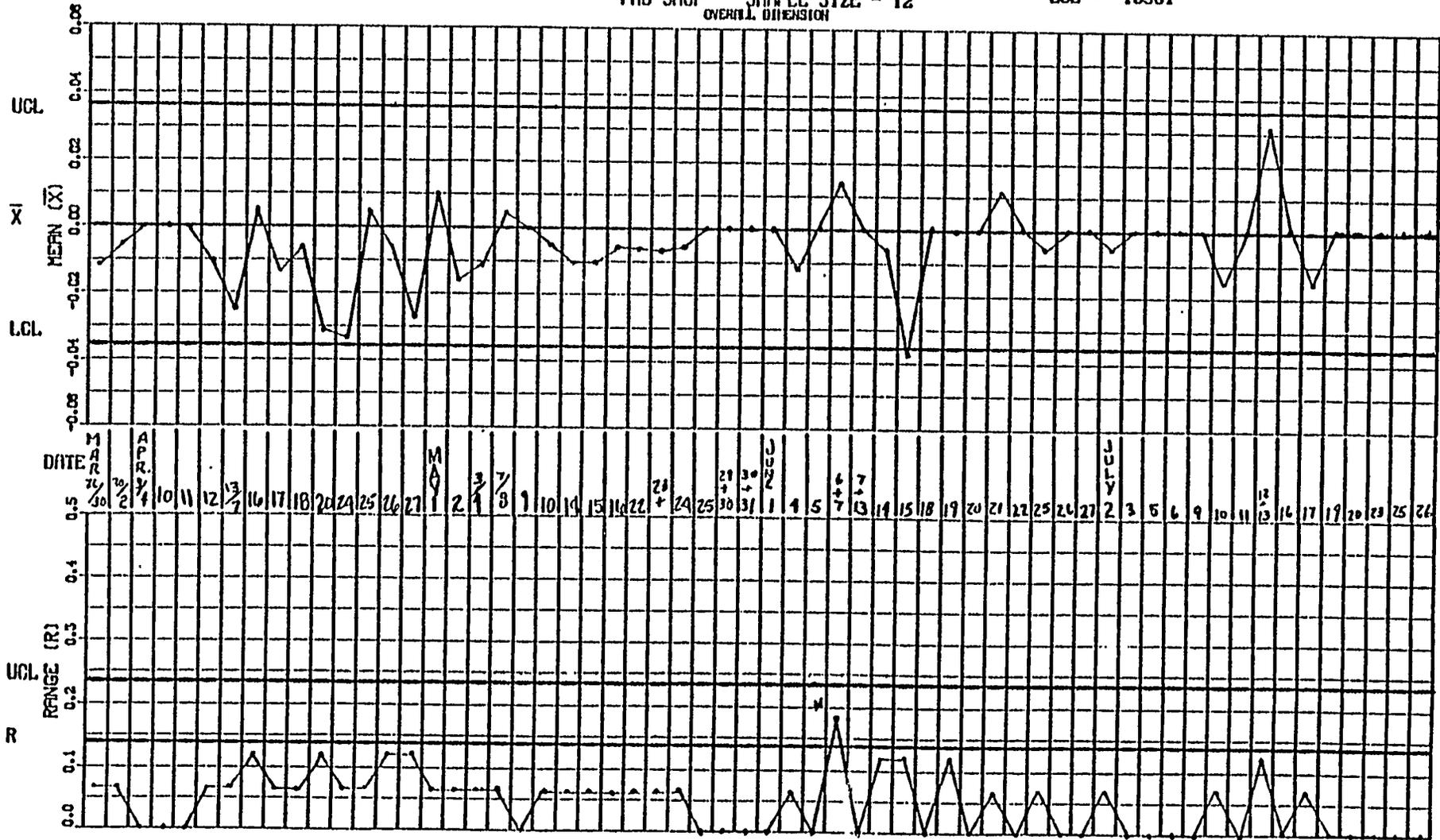
\*Y.B. REPAIR 2/3/84  
 \*Y.B. REPAIR 2/7/84

EXHIBIT 3

ACCURACY CONTROL CHART  
 NO 1 ADM FIRST SHIFT  
 FAB SHOP SAMPLE SIZE - 12  
 OVERALL DIMENSION

X BAR CHART  
 $\bar{X}$  - 0.0  
 UCL - 0.0361  
 LCL - -0.0361

R CHART  
 R - 0.1350  
 UCL - 0.2331



\* 6/6 - CUT 6" SLAB + 3/16 FROM D6314N

The control charts were then used to identify any tendencies or variations in the operation of the machines. If the data indicated fluctuations beyond the control limits, the following options were exercised: (4)

- \* Complete a more detailed investigation of the data.
- \* Investigate methods of measurement and instruments used.
- \* Notify maintenance department for evaluation/repair of machinery.
- \* Notify planning department for evaluation of changes in assembly procedures.

The daily analysis of the machines resulted in improvements in both the operation and maintenance of each machine. A few interesting items which were either directly or indirectly related to this aspect of the program are:

- \* Slight variations in the data collected by different shift operators were thought to be caused by differences in measurement methods. After investigation, it was found that manual inputs, particularly kerf settings, were set differently by each operator. A standardized operation chart, listing various manual settings and nozzle/tip sizes vs. plate thickness has since been developed. Subsequently, collected data has been consistent, regardless of the operator.

- \* Control charts were posted at each machine, providing each operator with an idea of the quality of work he was producing. Since the data indicated that the machines were operating within the pre-established limits, workers in the "customer" areas of sub-assembly and final assembly had more confidence in the dimensional accuracy of the pieces they received.
  
- \* Increased awareness in the importance of burning quality resulted in the hiring of a burning consultant to retrain all burners in machine and hand torch techniques. Vendors were consulted with regard to providing better burning equipment and torch tips. Increased use of portable machines and burning templates resulted in on-ship improvements in burning quality.
  
- \* Control charts provided a quantitative yardstick for measuring the effectiveness of regular machine maintenance on each machine.

## 2. Statistical Database

The cumulative collection of data for each burning machine provided a process mean ( $\bar{X}$ ), variance ( $\sigma^2$ ), and standard deviation ( $\sigma$ ). By definition, standard range ( $\bar{X} \pm 2\sigma$ ) represents 95% of the variation of a normally distributed set of data, and tolerance range ( $\bar{X} \pm 3\sigma$ ) represents 99% of the variation of a normally distributed set of data (5). These values establish the normal work performance for each machine.

Exhibit 4 is a summary of the results obtained on each machine for the variation of overall dimensions from design. The percentages of values within  $0\pm 1/16$  inch and  $0\pm 1/8$  inch correspond to the ranges of our process standards.

Based on the results obtained from this program, it can be concluded that the repair and replacement of the burning machines have improved the dimensional accuracy of fabricated pieces leaving the shop (a 13% increase on the No. 3 ABM and a 25% increase on the new No. 4 ABM of pieces fabricated within  $0\pm 1/16$  of design). Our ability to provide statistical evidence of the machines capabilities has been partially responsible for our recent success in securing non-shipbuilding work for the shop during slack periods.

DIMENSIONAL CONTROL DATA SUMMARY

WORM PROCESS: Parts Fabrication

WORK STATION: No. 3 ABM

CHARACTERISTIC MEASURED; Overall Dimensions (length, width)

SAMPLE SIZE: 12 Measurements/Shift

PROCESS STANDARD: Standard Range:  $0 \pm 1/16$  inch

Tolerance range:  $0 \pm 1/8$  inch

(Machine spec.:  $0 \pm 1/16$  inch in 40 ft.)

PERIOD	AVERAGE	VARIANCE	STD. DEV.	% $0 \pm 1/16$	% $0 \pm 1/8$
1	- . 0 12 1	. 0289	$\pm .0425$	84.38	99.51
2 .	- . 0261	. 0364	$\pm .0477$	74.27	97.93
3	- . 0087	. 0397	$\pm .0498$	78 .35	98.67
4	- . 0 1 17	. 0307	$\pm .0438$	8 7 .15	99.42
5	- . 0343	. 0136	$\pm .0292$	96.57	99 . 80
TOT.	- .0135	. 03 13	$\pm .0442$	8 2 . 38	99.31

Period 1: 06/24/83 - 07/04/83 (n=346)

Period 2: 09/15/83 - 12/31/83 (n=634) 1st shift

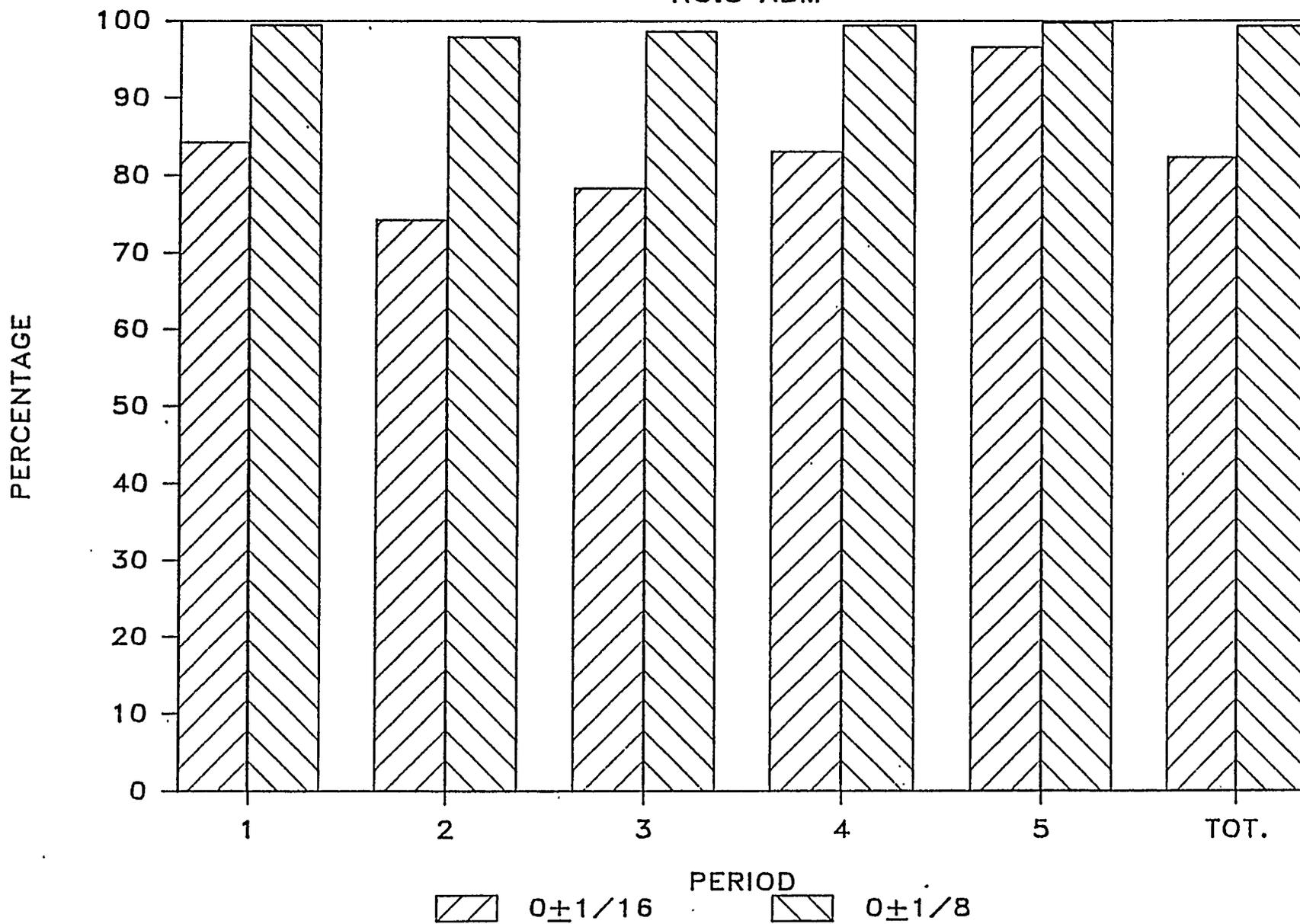
Period 3: 09/15/83 - 12/31/83 (n=588) 2nd shift

Period 4: 01/02/84 - 03/21/84 (n=354)

Period 5: 03/28/84 - 06/30/84 (n=482) Machine overhaul completed

# DIMENSIONAL CONTROL STUDY

NO.3 ABM



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EXHIBIT 4

DIMENSIONAL CONTROL DATA SUMMARY

WORK PROCESS: Parts Fabrication

WORK STATION: Inside Travo/No. 4 ABM

CHARACTERISTIC MEASURED: Overall Dimensions (length, width)

SAMPLE SIZE: 12 Measurements/Shift

PROCESS STANDARD: Standard Range:  $0 \pm 1/16$  inch

Tolerance range:  $0 \pm 1/8$  inch

(Machine spec.:  $0 \pm 1/16$  inch in 40 ft.)

PERIOD	AVERAGE	VARIANCE	STD. DEV.	% $0 \pm 1/16$	% $0 \pm 1/8$
1	-.0107	.0423	$\pm .0514$	76.60	98.27
2	-.0281	.0630	$\pm .0628$	63.39	93.09
3	-.0230	.0430	$\pm .0517$	72.69	97.35
4	-.0060	.0019	$\pm .0272$	97.53	99.80
TOT.	-.0184	.0412	$\pm .0507$	75.30	97.97

Period 1: 06/30/83 - 11/30/83 (n=240)

Period 2: 11/15/83 - 12/31/83 (n=514)

Period 3: 01/02/84 - 03/27/84 (n=778)

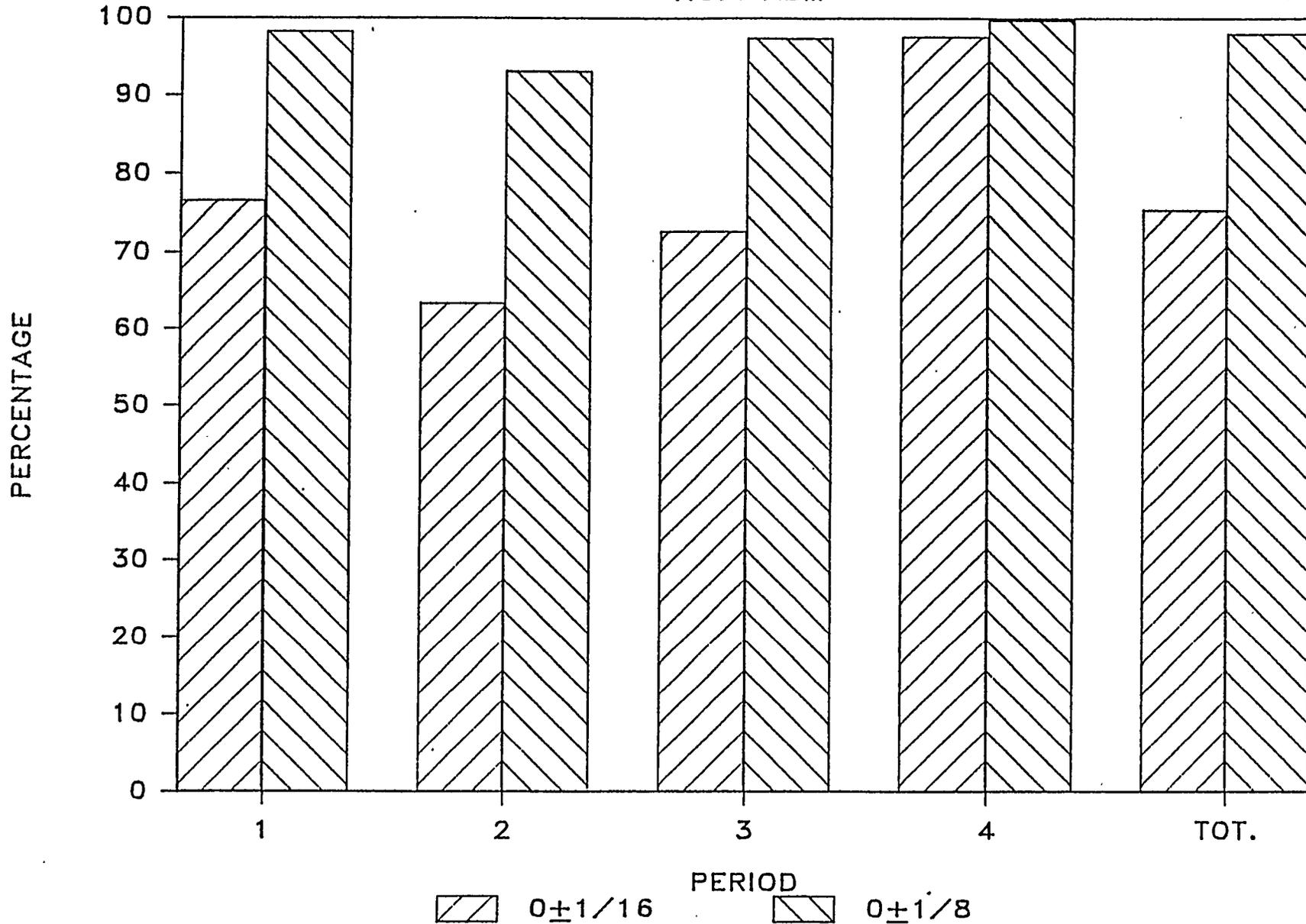
Period 4: 03/28/84 - 06/30/84 (n=510) New Machine

Period 4: 03/28/84 - 06/30/84 (n=482) Machine overhaul completed

EXHIBIT 4

# DIMENSIONAL CONTROL STUDY

NO.4 ABM



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EXHIBIT 4

## CONCLUSION

The value of this report does not lie in the numbers presented here, but rather in the methodology of controlling work processes through the collection and interpretation of data. The ability to make sound engineering and management decisions is directly related to the amount, the quality, and the format of the information that is available.

The expansion of a statistical quality control program to all shipyard work processes represents a significant commitment of resources by top management. It also represents a significant change from traditional methods to a more modern shipbuilding approach. The impact of such a change must be realized and accepted throughout all activities within the shipyard.

Japanese quality circles are dependent on everyone, workers included, to regularly and willingly participate in problem solving so as to constantly improve productivity. The possession of such capabilities in shops, is a tremendous competitive edge (6). This type of awareness and participation, as practiced by the Japanese shipbuilder's, can only be obtained through the education and training of each yard's most important resource; its employees.

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4. L.D. Chirillo, "Process Analysis Via Accuracy Control", U.S. Department of Transportation, Maritime Administration, February 1982, p.23
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6. L.D. Chirillo, "Testimony Submitted to U.S. House of Representatives Subcommittee on Merchant Marine and Fisheries", June 20, 1984, p.12

LIST OF EXHIBIT CAPTIONS

EXHIBIT 1      PROCESS LANES CATEGORIZATION

EXHIBIT 2      PROCESS CONTROL STANDARD

EXHIBIT 3      CONTROL CHART - NO. 3 ABM  
                  CONTROL CHART - NO. 4 ABM

EXHIBIT 4      DIMENSIONAL CONTROL DATA SUMMARY - NO. 3 ABM  
                  DIMENSIONAL CONTROL DATA SUMMARY - NO. 4 ABM

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