1.0 INTRODUCTION

1.1. General

Accuracy impacts on productivity. Thus, accuracy is a prime and continuing concern among professional shipbuilding engineers. They regard Accuracy Control (A/C), i.e., abilities to regulate accuracy, first and foremost as a management tool for continuously improving productivity.

Statistics is the branch of mathematics dealing with collection, analysis, interpretation and presentation of masses of numerical data. The methods of statistics are methods of applied mathematics. Shipbuilding engineers who manage A/C programs must at least understand college-level elementary statistics.

Other prerequisites pertain to the data needed. An A/C data base is a major investment. At first it requires systematic recording of thousands of measurements. Such efforts are expensive. They will deter traditional managers having short-term goals. These people are more likely to apply what they believe to be A/C as sporadic and unsophisticated preventive steps in response to one particular customer's requirement for a specific degree of accuracy.

Lack of long-term application negates the central importance of statistically-valid data which describes a shipyard's *normal* accuracy performances. Such data is the basis for continuing the collection of measurements by mathematically determined sampling and for continued analysis and interpretation.

Competitive shipbuilders regard their A/C data base as a capital investment and means of production every bit as indispensable as a crane or a building dock. The significant cost for starting an A/C program makes sense only when it is amortized over future projects just as any other large capital investment. Costs for continuing the collection of data as a normal part of a production process, are nominal because of the sampling techniques employed.

A/C cannot be effectively applied in the absence of a *product-oriented work-breakdown structure* which features interim products (i.e., fabricated parts and various subassemblies) classified by the *problem areas* their manufacture imposes. This is the singular means used by the world's most competitive shipbuilders to operate both real and virtual work-flow lanes for a high variety of objects in mixed quantities.[1]

Because the different interim-products are classified by common problem-areas, the same work situations are sufficiently repeated within each area for statistical treatment. Moreover, as sets of solutions, e.g., specific classes of worker skills and facilities, are matched to problem areas, A/C data is uneffected by variations that would otherwise occur.

Some product-oriented shipbuilders evaluate each proposed interim-product or a lot consisting of more than one, for its efficiency as a work package. *Productivity Value* (PV) is expressed by the formula

$$PV = f(T,N,Q)$$

where:

T = time allowed for its accomplishment,
N = number of units of resources, and
Q = quality of work environment and *accuracy specified for the interim product.*

The function (T,N,Q) is determined empirically and separately for each stage within each flow lane. Each necessarily considers the immediately preceding and following work stages.

Having PV vary directly with Q insofar as it applies to *accuracy specified for the interim product* seems to be a paradox. However, in this case Q relates to the efficiency of the tolerances specified with subsequent assembly work in mind. Are the tolerances too accurate? Are they accurate enough? A/C provides the method for determining the optimum tolerances required at each stage consistent with the needs of customers, regulatory societies and *productivity.*

When customers vary their accuracy requirements, as for different ships in different services, A/C provides quantitative means to change details and assembly sequences, and to adjust tolerances to suit. This ability to better control production through control of accuracy is a tremendous competitive edge.

[1] "Product Work Breakdown Structure - November 1980" by Y. Okayama and L.D. Chirillo for the National Shipbuilding Research Program.

A/C is a repeating cycle of *plan, execute, evaluate and replan*; Figure 1-1. Vital points and dimensions for blocks, sub-blocks and parts that are needed to assure accuracy of an end product are identified. They are systematically monitored at designated production stages. Similarly, many other measurements are made and carefully documented until scientifically-valid samples of accuracy data have been collected. The data are evaluated using statistical methods to verify performance in terms of *standard ranges* of accuracy normally encountered and *tolerance limits* beyond which rework is required. By including such written requirements in work instructions and by systematically monitoring, A/C "tightens up" all activities along a production line, e.g., template production, marking, cutting, bending, fitting, welding, and line heating so that the tolerance requirements for each are compatible with the others'. No longer are crucial judgements about accuracy left to opinions and guesses.

A specific example of "tightening up" for a particular work process was further development of line heating to *more accurately* form curved hull-parts as a means of minimizing erection work. Man-hours required for bending were reduced to almost one third those needed for conventional rolling or pressing, fewer clips, dogs, wedges, etc. were required by assembly workers, and rework for adjusting joint-gaps during hull erection was greatly reduced.

Where most effectively applied, A/C engineers are assigned thoughout the operations department. Because their methods are *analytical* and always address the *entire shipbuilding process* their recommendations are inherently apolitical. Thus, they have the best opportunities for developing themselves as *shipbuilding engineers*. As A/C experience is virtually prerequisite for higher managerial jobs, candidates are carefully selected from people having about eight years shipbuilding experience and memberships are rotated. This viable group, in addition to its day-to-day planning, executing and evaluating, functions as a defacto staff, i.e., advisory group, to the operations manager and his deputies.

A/C provides scientifically derived, written and realistically obtainable accuracy standards and goals. A/C is a function that transcends departmental responsibilities. Whether it should be adopted should not be left to department or shop managers whose concerns are parochial.

A/C reports contain essential and reliable data that measure critical aspects of production performance and indicate where improvements are required. Quite apart from controlling accuracy, A/C also defines management options regarding *all* aspects of an operations organization. Implementation requires total management commitment. In each shipyard, A/C should significantly preoccupy the most senior operations manager.

1.2 Basic Statistical Principles

When flat-bar parts are fabricated during work circumstances that are *controlled*, e.g., unchanged in facilities and worker skills, part lengths vary. Variations of specific magnitudes when plotted by the number of times they occur approximate a *normal distribution*; see Figure 1-2. Two useful characteristics which describe the relative shape of a normal distribution (N) are:

- its mean value, $\bar{x}$, the arithmetical average of variations in a sample, and
- its standard deviation, σ, which classes the sizes of variations from the mean value by their frequencies of occurance, e.g., 68% within a specific variation size, 95% within a larger size and so on.

Both characteristics are obtainable from mathematical formulas.

Similarly, spacings between longitudinals vary and another normal distribution having its own mean value and standard deviation applies; see Figure 1-3. Whether the variations in both flat-bar lengths and longitudinal spacings impose prospects for rework, depends upon their merger during a later assembly process.

Statistics provides a theorem for addition of two normal distributions which is used to obtain the normal distribution for fitting cut flat-bars between longitudinals; see Figure 1-4. Thus, a mean value and standard deviation can also be expressed for this latter assembly process. Further, the work process which contributed most to the final or merged variation is identified.

If there is need to reduce rework, accuracy goals are expressed in terms of the normal distribution required for the final process. Then, by working backwards necessary goals are similarly set for each of the work processes which would insure desired accuracy for the final process. Replanning flow lanes, improving work environments, retraining workers, etc., proceed accordingly.

Additions of normal distributions apply both to work processes necessary to insure needed accuracies of interim products, and to interim products themselves to insure required accuracy of a final product, e.g., a ship's hull. For the latter, the merged variation, Z, is expressed as:

$$Z = \Sigma Pi + \Sigma Si + \Sigma Ai + \Sigma Ei$$

where

- Σ Pi = merged variations from all part fabrication processes
- Σ Si = merged variations from all sub-block assembly processes
- Σ Ai = merged variations from all block assembly processes
- Σ Ei = merged variations from all erection processes

This equation is referred to as the variation merging equation for the completed hull.

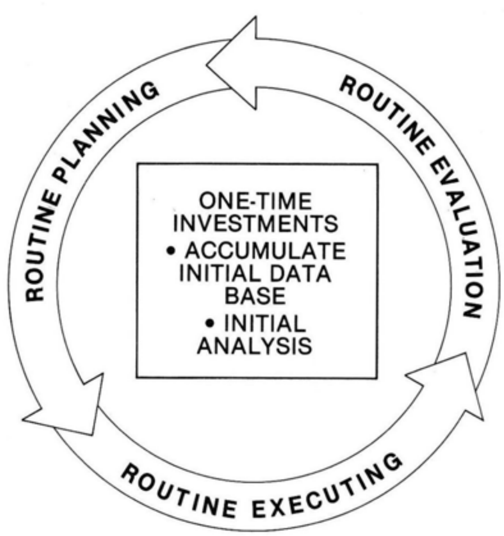

FIGURE 1-1: The A/C cycle is compatible with the management cycle of any industrial activity.

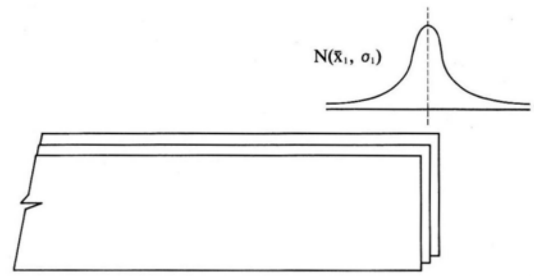

FIGURE 1-2: When a process for cutting flat-bar lengths is carefully managed so that it remains the same, variations from specified lengths occur in a normal pattern. Ignoring this reality causes impractical accuracy specifications and uncontrolled propagation of variations in succeeding work processes. Thus, competitive shipbuilders are now basing accuracy standards on the function $N(\bar{x}_1, \sigma_1)$, i.e., the normal distribution of variations.

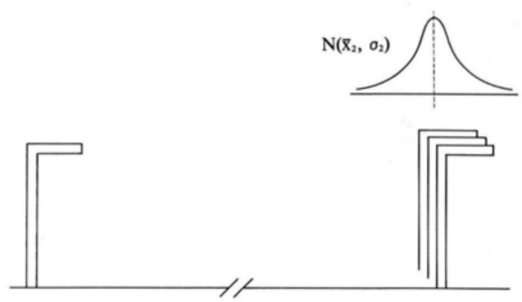

FIGURE 1-3: When a process for spacing apart longitudinals is carefully managed so that it remains unchanged, the variations in specified distances between longitudinals also approximates a normal distribution.

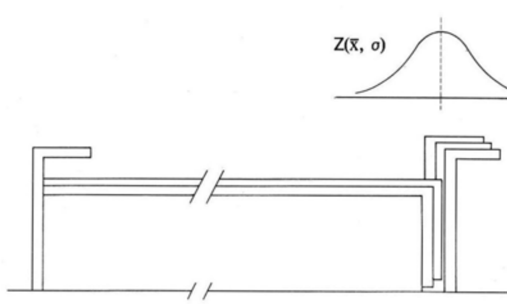

FIGURE 1-4: Competitive shipbuilders add normal distributions of variations from previous processes in order to predict how they merge at a later process.

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