2.0 APPROACH

Ships are built by procuring or fabricating parts and then joining them to create subassemblies. In turn, these are combined through several manufacturing levels to produce increasingly larger subassemblies and ultimately a complete ship. Competitive shipbuilders apply production-line techniques for the many different interim products required.

A production line is sequentially arranged work processes; it is a preplanned entity. Efficiency is dependent upon uniform work flow and coordination with other production lines. Optimum accuracy is crucial in order to avoid disruptive rework. Even nominal rework can break down the economic advantages of a production line. Thus, when thinking about how a ship is to be assembled, planners must address their shipyard's accuracy capabilities. A shipbuilder who has to compete, must support A/C planners with good systems for collecting and evaluating accuracy data.

In the absence of such measures the following typical questions are disregarded:

- What dimensions are vitally important to achieve required accuracy?
- How is the required degree of accuracy going to be achieved?
- In what work processes should vital dimensions be controlled?
- What are the tolerances that should be imposed at each work process?

Without tolerances specified for each process there is no way to control the accumulation of variations at a final process.

Tolerances in shipbuilding can be classified in two groups:

- *end-product tolerances* - some are fixed as by classification societies, and others which are invoked by owners can be negotiated, and
- *interim-product tolerances* - these are applied by a shipyard to insure compliance with end-product tolerances and simultaneously to *maximize productivity* (tolerances for productivity reasons are often more demanding than those imposed by classification societies and owners).

As a ship owner's guide to what can be achieved at reasonable costs for hull structure, Japanese shipbuilders, classification societies and universities collectively produced tables which:

- apply to many details, parts and subassemblies,
- are based upon actual data collected from participating shipyards,
- provide standard ranges of actual dimensions achieved which by definition reflect 95% probability for *normal* shipyard practice,
- provide tolerance limits which are criteria for rework, and
- are periodically revised to incorporate the impact of continuing improvements in shipbuilding technology.[1]

Ship owners have to pay more if they specify closer tolerances than those normally achieved as described in the foregoing.

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[1] "Japanese Shipbuilding Quality Standard (Hull Part) -1979" by the Research Committee on Steel Shipbuilding, the Society of Naval Architects of Japan. Per this document, 99.7% of the contributing shipyards' data is within tolerance limits, i.e., normally only 0.3% of the situations addressed in the Standard require rework.

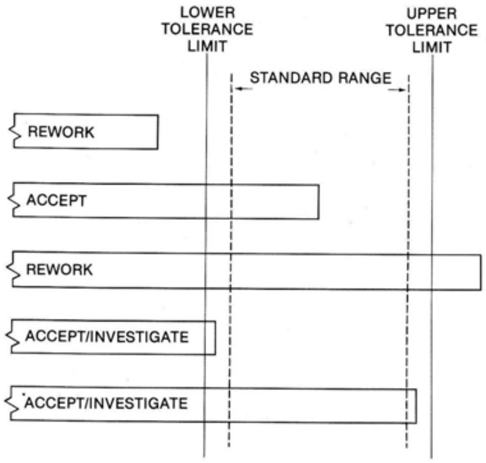

FIGURE 2-1: Accuracy exists in terms of a normally achieved range, i.e., a standard range. Learning how to work with ranges of variations is of great importanace, particularly for hull construction where shrinkages due to gas cutting, welding and line heating complicate sub-block assembly, block assembly and erection.

Standard ranges are indicated with the same plus and minus notations used to fix tolerances. However, they are not really tolerances. Instead, they reflect normal capabilities with 95% probability, of the processes used by the shipyards from which data was collected. Tolerance limits encompass their associated standard range as shown in Figure 2-1.

The use of ranges and limits as described in the foregoing is proven and acceptable to classification societies. Such use and continuing analyses of data enable Japanese managers to know where they are regarding accuracy being achieved and where they stand regarding acceptance. They know what they have to do next to improve their shipbuilding methods. Their abilities to regulate accuracy are a powerful means for managing shipbuilding operations.

Shipbuilders who wish to start an A/C program should limit startup to just midships or parallel midbody because interim products then:

- are generally simpler,
- are more numerous, and
- require fewer product-oriented work breakdown classifications.

Thus, the opportunities for reapplying the same work processes *without change* are greater. This is important because data collected for each specific work process must conform with a *test for normality*. Nonconformance with normal distribution indicates that a work process is insufficiently controlled. Something or someone has an erratic effect. Until this problem is solved, further statistical analysis is futile.

The most effective way to implement A/C is to focus on difficulties commonly encountered in joining blocks during hull erection. Erection-joint gaps that are not within tolerance limits must be reworked by gas cutting and/or back-strip welding as shown in Figure 2-2. Competitive shipbuilders have proven that applying A/C to all earlier work processes is more productive than having to deal with merged variation in relatively inaccessible and hazardous locations in a building dock.

Traditional *margins* to be trimmed at an erection site are regarded as commitments to rework so their use is minimized. Mostly, statistical methods are used to anticipate normal dimensional variations and to provide compensation such as *specific allowances for excess*. Most of the edges of parts, sub-blocks and blocks are finish cut accordingly.

A/C starts with statistical analysis of variations generated at each of the prerequisite work processes for hull erection, i.e., work processes during block assembly, sub-block assembly, part fabrication, lofting and design. First-time examination of actual measurements recorded for any work process, usually discloses that the variations:

- are greater than any manager imagined, and
- when plotted by frequency of occurrence vs. magnitude, usually follow the normal (Gaussian) distribution if the work process is repetitively applied without change.

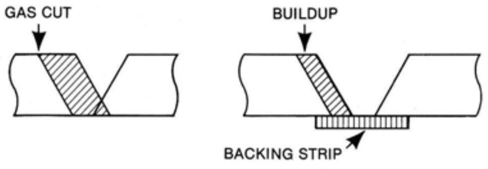

FIGURE 2-2: A/C focuses on minimizing rework on erection-joint gaps. The percentage of lineal measure of gas cutting and the percentage of lineal measure of back-strip welding, relative to the lineal measure of all erection gaps, are very effective productivity indicators.

Obtaining a mean value and standard deviation for each process, makes it possible to:

- express the standard deviation of variations at erection as a combination of the deviations of variations from preceding work processes,
- establish an order of priority for "tightening up" preceding work in order to reduce the accumulation of variations for the final work process.
- establish accuracy standards,
- revise written work and A/C procedures, and
- direct improvements in structural design-details in order to minimize requirements for high degrees of accuracy.

Generally work processes which require statistical analyses are:

•• *Part Fabrication*
- *marking*
  - marking method by template
  - ink marking
  - right angle tool and method
  - thread length and diameter
- *cutting*
  - tip nozzle and oxygen pressure
  - matching of rails and torch
  - machine error
  - height of torch above plate
- *bending*
  - shift of neutral axis
  - deformation of template
  - matching of templates
  - matching roundness of ends

•• *Sub-block assembly*
- *fitting*
  - gap at fitting
  - matching method by jig
- *welding*
  - welding condition
  - sequence of welding
  - fitting gap
  - level of platen
- *fairing*
  - method of fairing (e.g., line heating)

•• *Block Assembly*
- *plate joining and fitting*
  - degree of fitting gap
  - matching method by jig
  - level of platen
- *automatic welding*
  - running direction
  - condition of welding
  - leveling
  - method of securing angle
- *marking*
  - ink marking method
  - tool and method for right angle
  - thread length and diameter
- *cutting*
  - tip nozzle and oxygen pressure
  - matching of rails and torch
  - machine error
  - distance of torch from plate
- *assembly and fitting*
  - fitting gap
  - matching method of base line
  - leveling
- *welding*
  - condition of welding
  - sequence of welding
  - binding method
  - positioning apparatus
- *fitting of reverse-side members and welding*
  - positioning method
  - angle setting method
  - sequence of welding and condition

•• *Erection*
- *positioning*
  - cribbing arrangement and leveling
  - method of leveling
  - method of deciding inclination
  - slope of building berth
  - bending and twisting of block
  - rectangularity of hull body
- *welding*
  - condition of welding
  - sequence of welding
  - joining gap and shape of edge preparation

As shown in Figure 2-3, any A/C activity can be classified into one of three basic management functions that are inherent in any industrial enterprise:

- planning,
- executing (field work), and
- evaluating (analyses and feedback).

Thus A/C responsibilities can readily and effectively be incorporated in any existing organization provided:

- one manager, has responsibilities for *all*, not just A/C, planning, executing and evaluating operations,
- planning includes design and material definition, and
- within organizations such as a hull-structural design section, production-planning group or sub-block assembly section, people with pertinent engineering qualifications are assigned specific and substantial A/C responsibilities.

Effective A/C is critically dependent on unified operations, organized information and qualified incumbents. A special A/C organization is not a prerequisite. But, people throughout a shipyard who are assigned A/C responsibilities must at least function as a defacto A/C group. The person who maintains the principal A/C overview for an operations manager is a key individual.

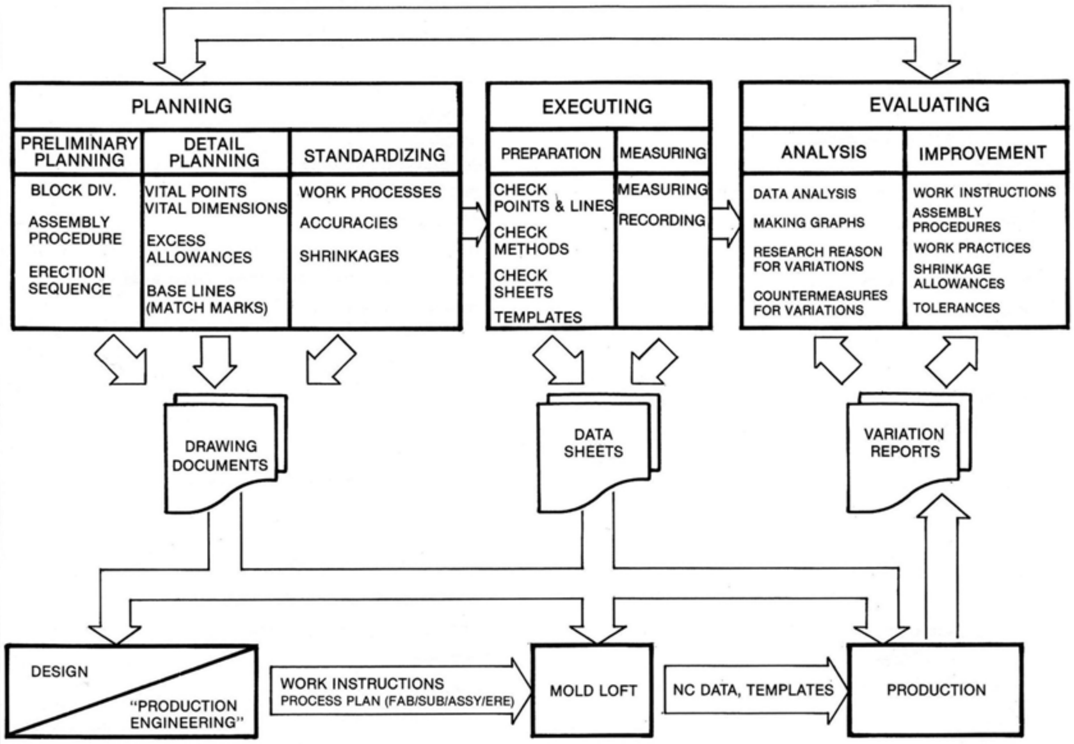

FIGURE 2-3: An A/C cycle is analogous to the basic management cycle for any industrial process. A single manager in charge of planning, executing and evaluating for other activities also, is prerequisite for effective A/C.