3.0 PLANNING

Figure 3-1 shows when A/C activities are applied during earlier work stages in order to minimize rework at the erection stage. Basically, what is shown is the role of A/C planning to:

- pinpoint what vital points and dimensions are critical to the dimensional and geometrical accuracy of blocks,
- designate critical check points and reference lines in blocks and in the sub-blocks and parts from which blocks are assembled,
- specify locations for and amounts of excess allowances,
- decide where and how much margin is to be used and the specific stages at which margins should be cut neat,
- determine work processes during which check measurements will be made,
- fix the numbers of interim products that should be measured based upon random sampling, and
- incorporate tolerance limits, excess allowances and margins in work instructions.

A/C planning is best performed together with other planning elements provided it receives at least the same emphasis. For effectiveness, specific A/C responsibilities should be clearly defined and specifically assigned to individuals. As previously shown in Figure 2-3, A/C planning can be divided as other major planning aspects into:

- preliminary planning,
- detail planning (preparation of work instructions), and
- standardization.

3.1 Preliminary Planning

Preliminary planning addresses such matters as block divisions, hull straking, and assembly procedures. Necessarily, preliminary planners must consider among other things:

- how to create blocks that facilitate shipwright work,
- how to strake the hull shell in order to design hull plates that can be accurately formed by available bending facilities and techniques, and
- how to shape blocks that are spacious and open to facilitate zone outfitting.

In order to carry out such studies systematically, drawings such as a general arrangement, midship section and lines and proposed schemes for block divisions and shell straking, are provided by designers to the planners who are assigned at the hull-construction department level and to the parts-fabrication shop, sub-block assembly section, block assembly section and erection section. As a routine matter the same information is equally available to the specific engineers among the planners who have been assigned A/C responsibilities. They apply analytical techniques based upon statistically obtained assessments of normal accuracy performances and propose optimum design details, assembly and erection sequences, tolerances etc., accordingly. The final scheme is fed back to designers who then develop key plans, such as a shell expansion, a block plan and ultimately work instructions all of which contain A/C derived requirements.

3.2 Detail Planning

A/C considerations in detail planning are really process analyses from an A/C viewpoint. Through such analyses problems which can be solved by regulating certain dimensions, are revealed in advance. In other words, in order to obtain required accuracy for a final process it is necessary to first identify the specific preceding processes that are mostly contributing to a final or merged variation. Thus A/C analyses identify on a quantitative basis, both the work processes and design details which should be improved.

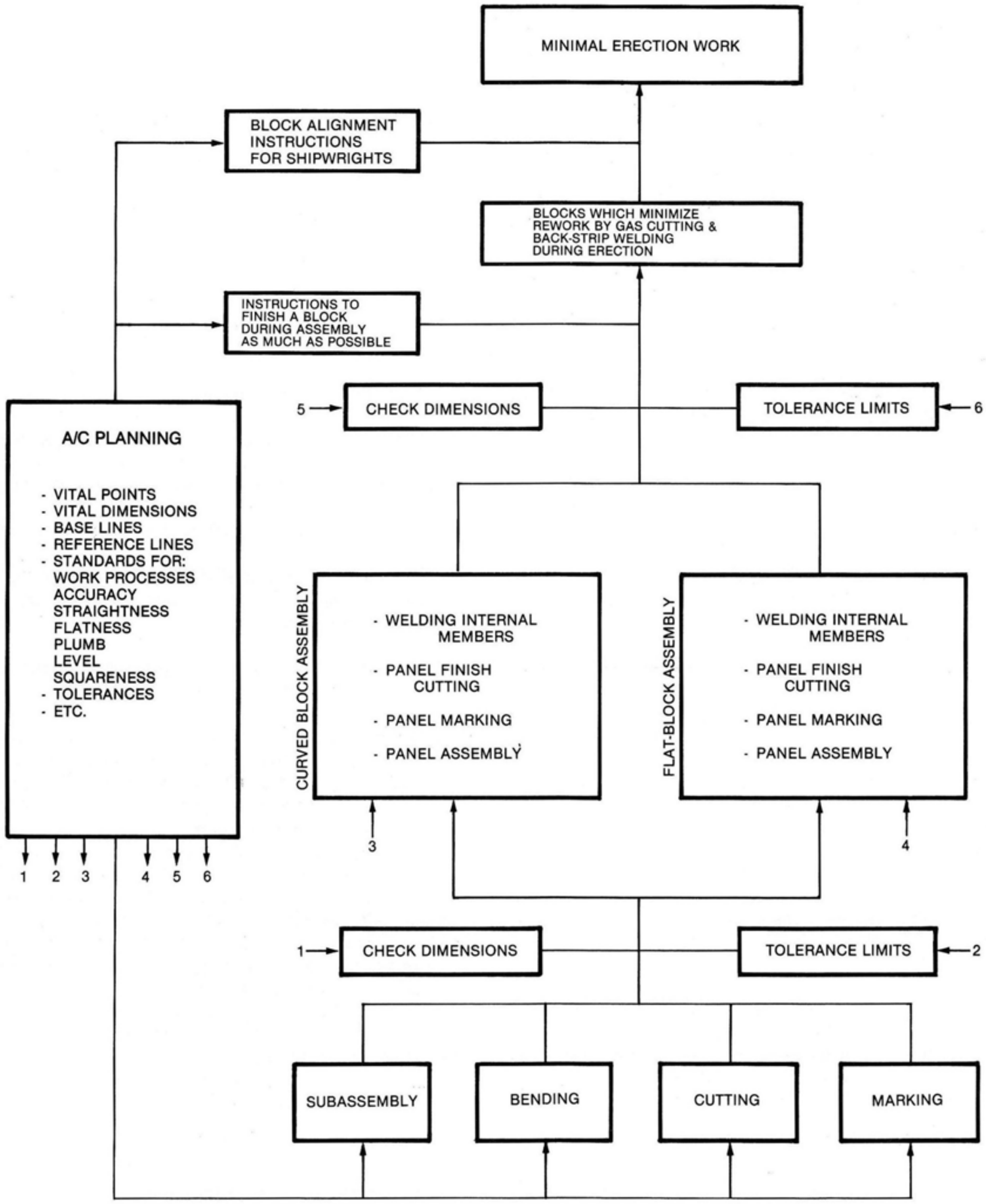


FIGURE 3-1: In addition to defining how to count (statistically), A/C defines what to count and when (at what stage) to count.

Of course, such determinations are not made solely from an A/C viewpoint. A/C techniques are analytical management tools that contribute to process analyses. They are means for a shipyard as an entity to capture and scientifically derive benefits from its accuracy experiences. The alternative is to have such experiences just vested in individuals who can demonstrate some pertinent, *parochial* expertise, but who can only guess about how their accuracy achievements impact on other work processes. A/C methods in detail planning are significant because they inherently address the entire hull construction process for the purpose of reducing erection work.

Planning proceeds by first assessing the accuracy characteristics for an end-product as specified by a regulatory society and ship-owner. Thinking of reverse process flow, A/C planners identify vital points and dimensions that must be maintained during erection, block assembly and so on as further described in Appendix A. In consideration of such vital aspects A/C planners insure that via work instructions and other means, loftsmen and people having A/C field responsibilities, are provided with necessary information such as check points and reference lines that must be included in numerical control (N/C) data, templates and field check-sheets.

Engineers who perform A/C planning for construction of a ship, recognize that most accuracy variations in work processes are normal and their impact on an end product can be predicted through statistical methods. The statistical terminology, notations and formulas included in the following passages, are further explained in Appendix B.

Simultaneously with the designation of required work procedures for a specific interim product, tolerances and amounts of excess are determined by taking into account the merging of variation. Variations generated by each work process follow a normal distribution, $N(\bar{x}_i, \sigma_i)$, and accumulate as another normal distribution, $Z(\bar{x}_0, \sigma_0)$, at the last stage. In order to reduce the merged variation, Z, it is necessary to reduce the standard deviation, σ_i, and control the mean value, $\bar{x}_i$, of each process considering their effects on current production methods. The standard deviations for all earlier processes, σ_i, are related to the standard deviation for the final process, σ_0, by the theorem of *addition of variance* where variance is simply the square of the standard deviation:

$$\sigma_0^2 = \Sigma\, \sigma_i^2$$
$$\text{or } \sigma_0 = \sqrt{\Sigma\, \sigma_i^2}$$

This jargon is the basis for employing variation merging equations in the practical world. An example of how A/C planners are already using them to predict merged variation in a bottom butt, to be joined during hull erection, is shown in Figure 3-2. Additional examples are contained in Appendix C. Included, are examples of how "A/C" process-analysis leads to design improvement and how a change in sequence can reduce the number of work processes required.

A/C planners also apply their abilities to predict merged variation within every manufacturing level. For example, for block assembly they use the normal distributions for each work process, i.e., panel assembly, panel marking, panel finish-cutting and internal-member welding, to predict the normal distribution for blocks currently being planned. The same technique is employed for sub-block assembly and for part fabrication.

As a consequence of their improved foresight, A/C planners advise designers of specific A/C matters that are to be included in work instructions. Although written descriptions are frequently necessary, symbols such as shown in Figure 3-3 are useful.

3.3 Standardization

3.3.1 Work Standards

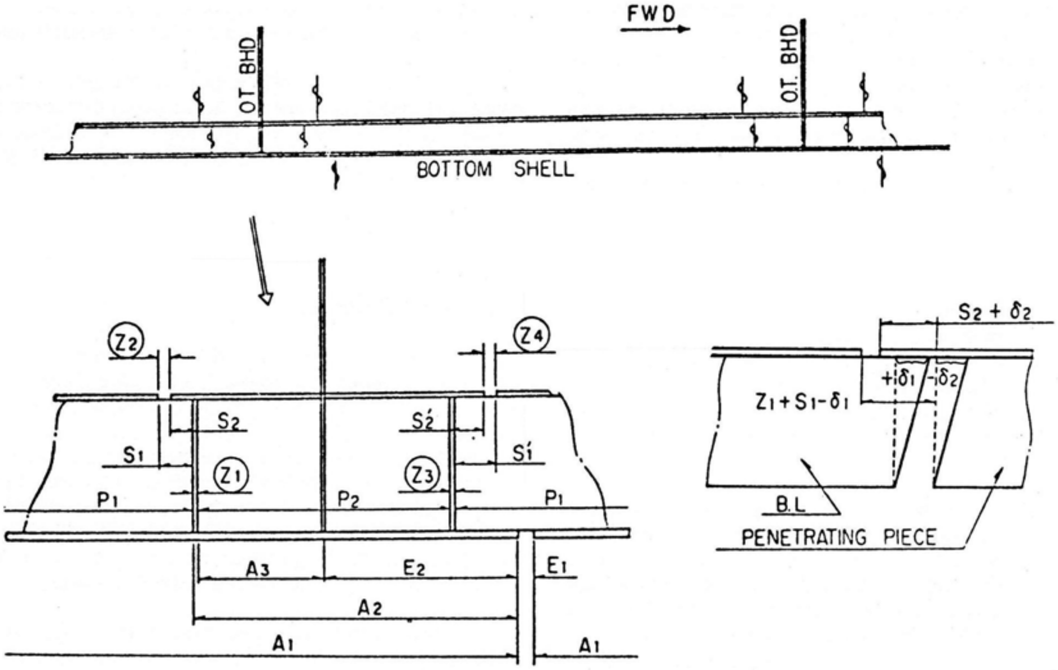
Any work process performs with varying degrees of accuracy. When it is *controlled* so that it is always applied the same way, variations will be normally distributed and can be analyzed based on the laws of statistics. Thus a crucial part of A/C is to insure that accuracy variations remain random and are not the result of arbitrarily introduced bias. Standardization of work processes and monitoring to insure compliance, are fundamental concerns of A/C people. "A/C" authorization of a proposed change in any work process, insures scientific analysis of its impact on the entire shipbuilding process.

This rigid control does not mean that changes are not made. Instead, adjustments to work processes are more frequent due to the continuous process analyses and feedback which are inherent features of A/C.

Related standards should be written and adhered to for such matters as:

- planned steel flow,
- worker organization,
- worker training, and
- supervision.

All, if changed without regard for "A/C" analyses and approvals introduce biases which invalidate any approach to A/C.



Assembly Procedure:

1. Fit the flange on the web shifted by S_1 (fwd end of longitudinal).
2. Fit the flange on the web shifted by S_2 (aft end of penetrating piece).
3. After the plates are welded together to create the bottom panel, incorporate a 3mm excess allowance and finish cut the panel's forward edge.
4. Fit the longitudinals to the bottom panel shifted by A_2 where A_2 = the designed dimension + 2mm.
5. Fit the penetrating piece to the transverse bulkhead at the distance A_3.

Variation Merging Equations for the Joint Gaps During Hull Erection:

$$Z_1 = A_2 - (A_3 + E_2)$$

$$Z_2 = Z_1 + [(S_1 - \delta_1) - (S_2 + \delta_2)]$$

$$Z_3 = [E_2 - (P_2 - A_3)] - [(P_1 + A_2) - (A_1 + E_1)]$$

$$Z_4 = Z_3 + [(S_1^1 - \delta_1^1) - (S_2^1 + \delta_2^1)]$$

- A negative value for Z predicts overlaps, i.e., negative gap.
- The value for every A, E, etc. is dependent upon a similar lower-tier equation which accumulates variations for marking, cutting, etc. as measured from a reference line.

FIGURE 3-2a: Variation merging equations are used to predict gap sizes which will occur during hull erection and probabilities for rework.

ESTIMATED MERGED VARIATION (Z)

Dimension	Sample size n	Mean value $\bar{x}$	Variance σ^2	Remarks
P_1	126	+0.4	0.91	Length of bottom longitudinal after web is welded to flange.
P_2	50	+0.5	0.79	Length of penetrating piece after web is welded to flange.
δ_1, δ_2	156	0	0.51	Perpendicularity of bottom longitudinal and penetrating piece ends.
δ_1', δ_2'				
S_1	140	+1.1	0.61	Fitting position of bottom longitudinal flange.
S_1'	140	+0.5	1.61	Shift between web and flange at the after end of bottom longitudinal.
S_2	50	−0.4	0.81	Fitting position of flange of penetrating piece.
S_2'	50	+0.6	1.82	Shift between web and flange at the forward end of penetrating piece.
A_1	36	+2.9	1.38	Length of bottom panel after finish cut.
A_2	83	+1.6	1.64	Fitting position of bottom longitudinal.
A_3	70	−0.8	2.02	Fitting position of penetrating piece.
E_1	42	−0.4	2.43	Accuracy of gap between bottom panels measured between reference lines after welding.
E_2	44	+1.9	4.60	Erected position of Transverse Bulkhead; Distance from butt of bottom panel.
Estimated Gap				
Z_1	_____	+0.5	8.26	_________ _________ * 7%
Z_2	_____	+2.0	10.70	_________ _________ * 17%
Z_3	_____	+1.0	13.79	_________ _________ * 14%
Z_4	_____	+1.0	18.22	_________ _________ * 17%

* Estimated occurrence of gaps which are 5 or more mm wide; back-strip welding is required. The method for calculating these estimates is described in Appendix E, Figure 8.

ACTUAL MERGED VARIATIONS

Actual Gap	Sample size n	Mean value $\bar{x}$	Variance σ^2	Actual occurence of back-strip welding
Z_1	85	+0.8	7.61	4%
Z_2	82	+2.3	9.71	12%
Z_3	78	+1.1	10.02	6%
Z_4	72	+2.2	13.75	13%

FIGURE 3-2b:

Stage	Description	Abbr.	Remarks
Lofting	Dimension Accuracy	1	Standard σ = 0.5 Shows Allowable ± 1 m/m
	Ditto	2	Standard σ = 0.7 Shows Allowable ± 1.5 m/m
Marking	Ditto	3	Standard σ = 1.0 Shows Allowable ± 2 m/m
Cutting	Material Angle Accuracy	ANGLE	Standard σ = 0.5/1000 Shows Allowable ± 1/1000
	Material Shape Accuracy	SHAPE	Standard σ = 0.7 Shows Allowable ± 1.5 m/m
Sub-block Assembly	Fitting Accuracy for Providing FC PL		Standard σ = 0.7 Shows Allowable ± 1.5 m/m
	Fitting Angle Accuracy	ANGLE	Standard σ = 1/1000 Shows Allowable ± 2/1000
	Edge-Fitting Accuracy	EDGE	Standard σ = 1.0 Shows Allowable ± 2 m/m
	Edge Straightness Accuracy	STRAIT	Standard σ = 1.0 Shows Allowable ± 2 m/m
Block Assembly	Dimension Accuracy Fitting Line Accuracy Other Accuracies	NB	Allowable ± 1∼ ± 2 to be described in stage plan, accuracy plan and other plans as nota bene
Hull Erection	Shipwright Accuracy Level Accuracy Accuracy between Vital Lines Main structure Fitting Accuracy Inner structure Fitting Accuracy Other Accuracies		

FIGURE 3-3: A/C symbols for work instructions.

In shipyards which are not competitive almost all of the problems found in production are caused by the absence of:

- *Standards for Excess*

At the startup of A/C activity the following questions are appropriate:

- Why are margins needed?

- Where are margins required?

- How much margin is necessary?

- During what work process will margins be finish-cut?

Usually, a margin scheme for main strakes, such as shell plates, is created by production planners. Margins shown are for ordering materials and/or fabricating parts. However, the amounts of margin are not prescribed by written standards that are backed up by records of measurement data. In this respect margins differ from *excess* allowances. Margins are used as a buffer to compensate for accuracy variations in all hull construction processes including design. Therefore, the true causes of accuracy variations and ways to improve fabrication methods are difficult to detect. Where A/C is not applied, the large amounts of margin used are based on "rough check" data which characterizes feedback from production. This vicious cycle disallows opportunities for improvements.

A/C scrutiny shrinks margins until most of them become just the excess allowances needed to compensate for variations. Excess is characterized by finish cutting based on a high probability that no rework will be required. When this transition is achieved, in order to further eliminate rework, A/C continues to impose the same questions:

- Why is excess needed?

- Where is excess needed?

- How much excess is necessary?

- If needed, during what stage should rework take place?

This incessant questioning is motivation for continuous improvements in work methods.

- *Standards for Shrinkage Allowance*

The amount of shrinkage caused by welding will be different depending upon materials, methods and sequences. Thus, shrinkage allowances are meaningless unless they are based upon recorded data for each set of circumstances.

- *Standards for Baselines and Match Marks*

  Even where the necessity and importance of baselines and match marks are recognized, their locations and lengths do not sufficiently reflect the production requirements that should be described in a standard.

- *Standards for Checking Procedures*

  A written checking procedure assures specified accuracy at each work process. Because no written checking procedures exist, few measurements are recorded for analysis.

- *Standards for Fabrication and Assembly Schemes*

  The sequences for sub-block assembly and block assembly are usually indicated by a numbering system, useful for computer processing, which is hierarchical in order to match ascending manufacturing levels. This system is good enough to indicate a simple sequence such as part fabrication, sub-block assembly, block assembly and erection, but it does not address vital points and dimensions needed to achieve specified accuracy during each work process.

- *Standards for A/C Information in Work Instructions*

  Usual hull-construction drawings show structural details and sometimes include instructions for edge preparations. Specific excess allowances are generally not included. Little other guidance is provided by designers to indicate fabrication methods and vital points and dimensions needed to achieve a specified degree of accuracy.

  Working drawings are the only widely distributed documents provided to workers which can display total instructions for how to construct a ship's hull. When design is recognized as an aspect of planning, working drawings will develop more as work instructions which facilitate employment of less-skilled workers, adherence to work standards, A/C analyses and continuous improvement in production methods.

3.3.2 Accuracy Standards

In order to control the accumulation of variations or merged variation at a final stage, accuracy standards are established for preceding work processes. Data obtained during construction of other ships is used to derive accuracy standards for a contemplated ship. However, these are reviewed by analyzing data recorded as production commences and progresses. Adjustments are made if assumed accuracy standards are manifestly unrealistic.

The concept of a *standard range* with a *tolerance limit*, as shown in Figure 2-1, is applied to every work process. The more demanding standard range is used as the accuracy standard for each particular work process in order to insure control of the merged variation at erection. By definition, standard range is associated with high probability ($\bar{x} \pm 2\sigma$ or 95% for shipyards in Japan).

Of the few remaining variations, those outside the standard range which do not require rework during the next work stage nor spoil end-product accuracy, are acceptable and are regarded as being within a tolerance limit. In other words, a tolerance limit because it applies to *fewer* cases includes some added allowance for acceptance. However, such limits must be achievable with normal production capabilities and must not impair structural integrity of the end product.

This approach recognizes basic realities in any industrial enterprise. While more demanding accuracy standards are applied to normal operations, some allowance is made for the effect on accuracy by on-the-job trainees, newly developed machines, etc. The concept of a standard range with a tolerance limit encourages managers to react to trends away from normally achieved accuracy *before* rework is required.

Typical standard ranges and tolerance limits that are employed for standardization by Japanese shipbuilders are tabulated in Appendix D. These standards, because they have been revised five times in thirteen years, reflect constant "A/C" scanning of work processes which forced industry-wide advances in shipbuilding technology. The constant upgrading is a measure of competition between national shipbuilding industries.

Some shipbuilders further developed the accuracy standards to address more design details and to further "tighten" work processes as a means for competing with each other. Pertinent samples are also included in Appendix D. The extent of this independent, further development of accuracy standards is a measure of competition between shipyards.

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