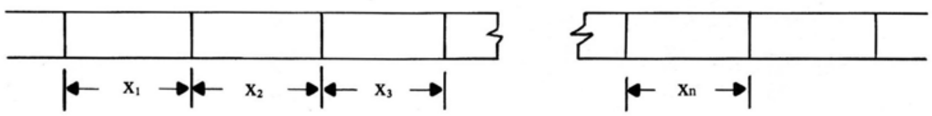
APPENDIX B

STATISTICAL CONCEPTS IN ACCURACY CONTROL

Performing basic statistical analyses requires understanding of three statistical concepts, mean, standard deviation and the normal distribution curve. Consider the process of marking and cutting flat bars of identical nominal length. Each piece has a measureable difference in length due to the inherent limitations of marking and cutting.



If *n* of these flat bars are measured, the mean length is:

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

and the standard deviation is:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}}$$

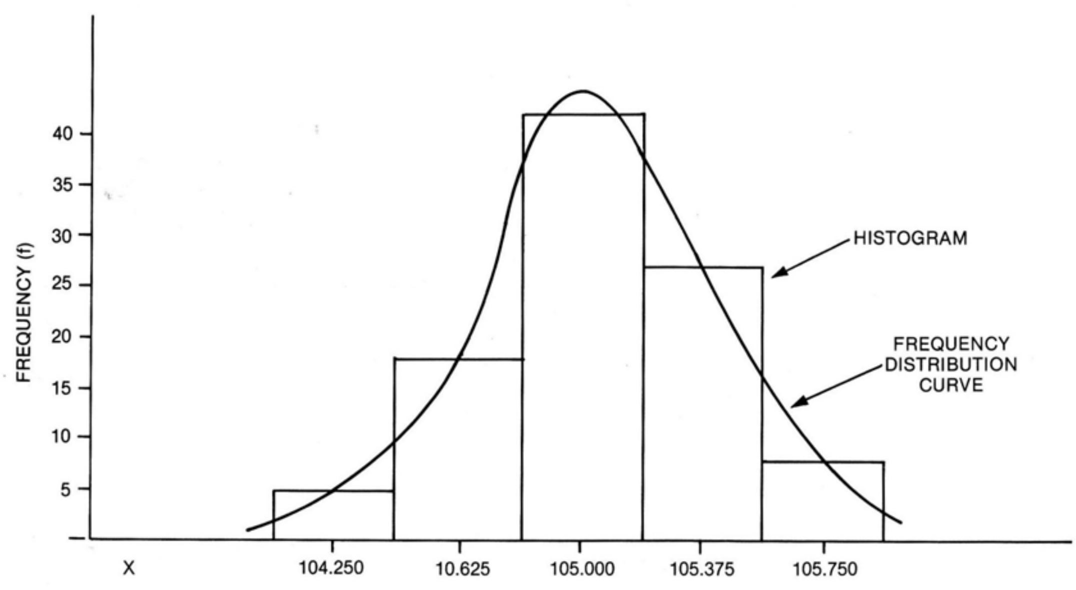
These two values, the mean and standard deviation, are for a random sample of size *n*. The random sample is taken from the population of all flat bars produced by a specific process. The population can be considered as infinite in size, with the random sample a finite subset. This sampling procedure can be repeated with a different batch of flat bars, measuring their lengths and calculating a new mean and standard deviation. Generally, the means and standard deviations of the two random sample will not be identical. In theory, an infinite number of random samples of size *n* could be taken and their means and standard deviations calculated. The laws of statistics state that the mean of all those means will be identical to the mean of the entire population of the flat bars, i.e., all flat bars ever made by a specific, unchanged work process.

Raw data must be grouped to facilitate handling and analysis. Grouping data avoids the need for establishing precision limits and has other advantages. Data grouping is done by measuring the length of each piece in the sample, arranging the data into length classes, and determining the number of flat bars belonging to each class. The result is tabulated on a frequency distribution table and is graphically represented by a frequency diagram or histogram.

The frequency distribution represents the number of occurrences of flat bars in each length class. Given a perfectly controlled process, the frequency distribution will be a *normal distribution*. Where not perfectly controlled the frequency distribution for a sample of measurements can be used to approximate the normal distribution for the process. The following table, histogram, and frequency distribution are examples associated with measuring the length of 100 flat bars:

FREQUENCY DISTRIBUTION TABLE

Length Classes (inches)	Midpoints (x)	Frequency (f) (number of pieces)
104.125 - 104.375	104.250	5
104.500 - 104.750	104.625	18
104.875 - 105.125	105.000	42
105.250 - 105.500	105.375	27
105.625 - 105.875	105.750	8
		Sample size: 100



The area enveloped by the curve represents the total number in the sample. Generally, a distribution curve obtained from actual data is not perfectly bell shaped as is the case for a normal distribution. As explained in Attachment 1, there is a way to best fit a normal distribution and determine the pertinent risk factor.

Assuming that the example data is acceptable, the mean value ($\bar{x}$) of the sample is simply the average length or representative length of all flat bars in the sample. When data is grouped by frequency of occurrence the mean is defined as:

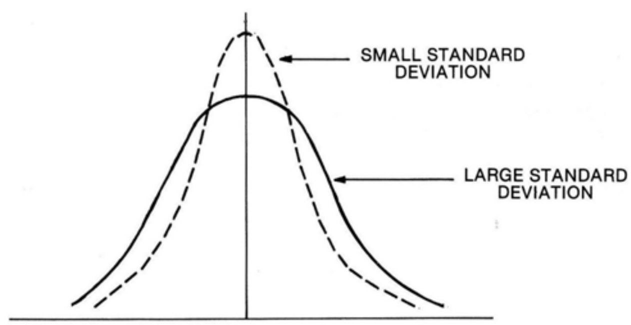
$$\bar{x} = \frac{f_1 x_1 + f_2 x_2 \ldots + f_n x_n}{n}$$

and for the example

$$\bar{x} = \frac{(5 \times 104.250) + (18 \times 104.625) + (42 \times 105.000) + (27 \times 105.375) + (8 \times 105.750)}{100}$$

$$\bar{x} = 105.056 \text{ inches}$$

The second fundamental parameter is standard deviation which is a measure of the dispersion or scatter of the observed values around the mean value. If all observed lengths of flat bars tend to concentrate near the mean, the standard deviation is small. If the values tend to be distributed far from the mean, the standard deviation is large.

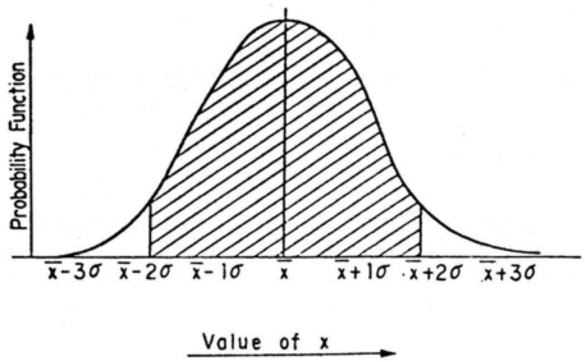


Standard deviation is defined as:

$$\sigma = \sqrt{\frac{f_1 (x_1 - \bar{x})^2 + f_2 (x_2 - \bar{x})^2 \ldots + f_n (x_n - \bar{x})^2}{n}}$$

for the example when x = 105.056
σ = 0.365

Random variations from a well controlled process follow the normal distribution which is a symmetrical, bell-shaped curve defined by its mean and standard deviation. The area beneath the curve always represents 100% of the sample being considered apportioned as follows:



The area between:
$\bar{x}$-σ and $\bar{x}+\sigma$ (one standard deviation) = 68.27%
$\bar{x}$-2σ and $\bar{x}+2\sigma$ (two standard deviations) = 94.45% (shaded)
$\bar{x}$-3σ and $\bar{x}+3\sigma$ (three standard deviations) = 99.93%

These values can be obtained for any value of × from tables incorporated in statistics texts.

APPENDIX B, ATTACHMENT 1

The distributin of controlled processes can be shown to be a normal distribution by applying the "goodness-of-fit" test as a test for normality. This involves calculating the *chi-square* statistic:

$$\chi_o^2 = \sum_{i=1}^{k} (o_i - f_i)^2 / f_i$$

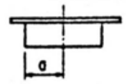
where k = *number of ranges in measured frequency distribution*
o_i = *frequency of observations in each range*
f_i = *expected frequency in each range for an exactly normal distribution*

This χ_o^2 statistic is then compared to χ^2 statistic for a pre-chosen level of significance (α) for k - 1 degrees of freedom. Data in the following table confirm that the variations in shipbuilding work processes do follow the normal distribution. The level of significance, $\alpha = 0.05$, is the risk factor. That is, there is only a 5% chance that the goodness-of-fit test will indicate a normal distribution when one does not exist.

SPECIFIC CHARACTER AND CHECK OF NORMALITY

MAJOR PROCESS	MINOR PROCESS	PARTS	SPECIFIC CHARACTER	MEASURING STANDARD	RESULT OF MEASURE		TEST FOR NORMALITY	
					AVERAGE	STANDARD DEVIATION	χ_0^2/χ^2 (α .05)	LEVEL OF SIGNIFICANCE TO χ_0^2
HULL PREFABRICATION PROCESS	MARKING AND GAS CUTTING PROCESS	HULL PROPER	RIGHT ANGLE OF FINAL MARKING PLATE	DEFRECTION PER ONE METER LENGTH	0	0.91 / 1000	$\chi_0^2 = 1.34 < \chi^2(4.05) = 9.49$	80 – 90 %
			LENGTH OF FINAL MARKING PLATE	+ IS OVER, – IS LESS REGARDING DIMENTION IN DWG OR TAPE AS 0	0.3	1.08	$\chi_0^2 = 5.73 < \chi^2(4.05) = 9.49$	20 – 30 %
			WIDTH OF PLANER PLATE	—— DITTO ——	0.1	0.69	$\chi_0^2 = 7.68 < \chi^2(6.05) = 12.59$	20 – 30 %
			ANGLE OF EDGE PREPERATION	+ IS OVER, – IS LESS GIVEN 65 DEGREE AS 0	0.1	1.15	$\chi_0^2 = 2.64 < \chi^2(6.05) = 12.59$	80 – 90 %
		INTERNAL STRUCTURE	MARKING DIMENTION	+ IS OVER, – IS LESS GIVEN TAPE DIMENTION AS 0	0	0.55	$\chi_0^2 = 3.26 < \chi^2(2.05) = 5.99$	10 – 20 %
			SECTION STEEL MARKING DIMENTION	—— DITTO ——	0.3	0.74	$\chi_0^2 = 2.65 < \chi^2(3.05) = 7.81$	30 – 50 %
			CUTTING ACCURACY ALONG REFERENCE LINE.	REFERENCE GIVEN (50) AS 0	0.6	0.76	$\chi_0^2 = 4.85 < \chi^2(3.05) = 7.81$	10 – 20 %
			CUTTING ACCURACY FOR EDGE PREPERATION	—— DITTO ——	- 0.1	0.96	$\chi_0^2 = 2.40 < \chi^2(4.05) = 9.49$	50 – 70 %
			CUTTING ACCURACY FOR STRUCTURAL	—— DITTO ——	0.3	1.10	$\chi_0^2 = 2.40 < \chi^2(6.05) = 12.59$	80 – 90 %
			LENGTH OF BUILT UP LONGITUDINAL	+ IS OVER, – IS LESS GIVEN TAPE. DIMENTION AS 0	0.1	0.94	$\chi_0^2 = 5.25 < \chi^2(4.05) = 9.49$	20 – 30 %
	SUB-ASSEMBLY PROCESS		FITTING POSITION OF STIFFENER	STIFFENER	0.3	0.86	$\chi_0^2 = 3.47 < \chi^2(4.05) = 9.49$	30 – 50 %
			FITTING POSITION OF WFB FRAME FACE PLATE	ACCORDING TO DIMENTION SHOWN IN DWG.	0	1.40	$\chi_0^2 = 3.52 < \chi^2(4.05) = 9.49$	30 – 50 %
			—— DITTO ——	ACCORDING TO REFERENCE MARK	- 0.1	1.14	$\chi_0^2 = 2.98 < \chi^2(4.05) = 9.49$	50 – 70 %
			FITTING POSITION OF BUILT UP LONGITUDINAL FACE PLATE	ACCORDING TO DIMENTION SHOWN IN DWG.	- 0.1	0.89	$\chi_0^2 = 4.50 < \chi^2(4.05) = 9.49$	30 – 50 %

Continued

MAJOR PROCESS	MINOR PROCESS	PARTS	SPECIFIC CHARACTER	MEASURING STANDARD	RESULT OF MEASURE		TEST FOR NORMALITY	
					AVERAGE	STANDARD DEVIATION	χ_0^2/χ^2 (ø .05)	LEVEL OF SIGNIFICANCE TO χ_0^2
ASSEMBLY PROCESS	JOINTING, CUTTING PROCESS	HULL PROPER	BLOCK LENGTH (MARKING ACCURACY)	DEVIATION AGAINST MOLD TAPE	-0.1	1.25	$\chi_0^2=5.60<\chi^2(4.05)=9.49$	20 - 30 %
			BLOCK WIDTH (MARKING ACCURACY)	—— DITTO ——	-0.3	1.13	$\chi_0^2=1.21<\chi^2(4.05)=9.49$	80 - 90 %
			RIGHT ANGLE DEGREE AROUND BLOCK	DIFFERENCE BETWEEN BOTH DIAGONAL LENGTH	0.6	1.78	$\chi_0^2=6.90<\chi^2(5.05)=11.07$	20 - 30 %
			CUTTING ACCURACY	GIVEN REFENCE LINE (50) AS CORRECT	0	0.91	$\chi_0^2=2.59<\chi^2(4.05)=9.49$	50 - 70 %
	ASSEMBLING PROCESS	PANEL AND FRAMING	LENGTHWISE FITTING POSITION OF PARTS	GIVEN DIMENSION AS 0	0.1	1.41	$\chi_0^2=1.83<\chi^2(4.05)=9.49$	70 - 80 %
			TRANSVERSAL FITTING POSITION PARTS	—— DITTO ——	0	1.42	$\chi_0^2=5.56<\chi^2(4.05)=9.49$	20 - 30 %
			FITTING POSITION OF PENETRATION PARTS	 a	-0.4	1.70	$\chi_0^2=2.24<\chi^2(5.05)=11.07$	80 - 90 %
ERECTION PROSESS	SHIPWRIGHTING	BLOCK JOINTING	BOTTOM BLOCK SEAM (AT TACKING).	GIVEN DIMENTION BETWEEN REF. LINES (100) AS NORMAL	2.6	1.58	$\chi_0^2=2.76<\chi^2(3.05)=7.81$	30 - 50 %
			BOTTOM BLOCK BUTT (AT TACKING)	—— DITTO ——	3.0	1.86	$\chi_0^2=1.18<\chi^2(4.05)=9.49$	80 - 90 %
			L BHD BLOCK SEAM (AT TACKING)	—— DITTO ——	2.1	1.93	$\chi_0^2=3.48<\chi^2(4.05)=9.49$	30 - 50 %
			L BHD BLOCK BUTT (AT TACKING)	—— DITTO ——	2.8	2.22	$\chi_0^2=2.63<\chi^2(4.05)=9.49$	50 - 70 %
			UPPER DECK BLOCK SEAM (AT TACKING)	—— DITTO ——	2.5	1.82	$\chi_0^2=4.52<\chi^2(4.05)=9.49$	30 - 50 %
			UPPER DECK BLOCK BUTT (AT TACKING)	—— DITTO ——	2.7	2.04	$\chi_0^2=2.82<\chi^2(5.05)=11.07$	70 - 80 %

Refer to a statistics text for χ^2 distribution.

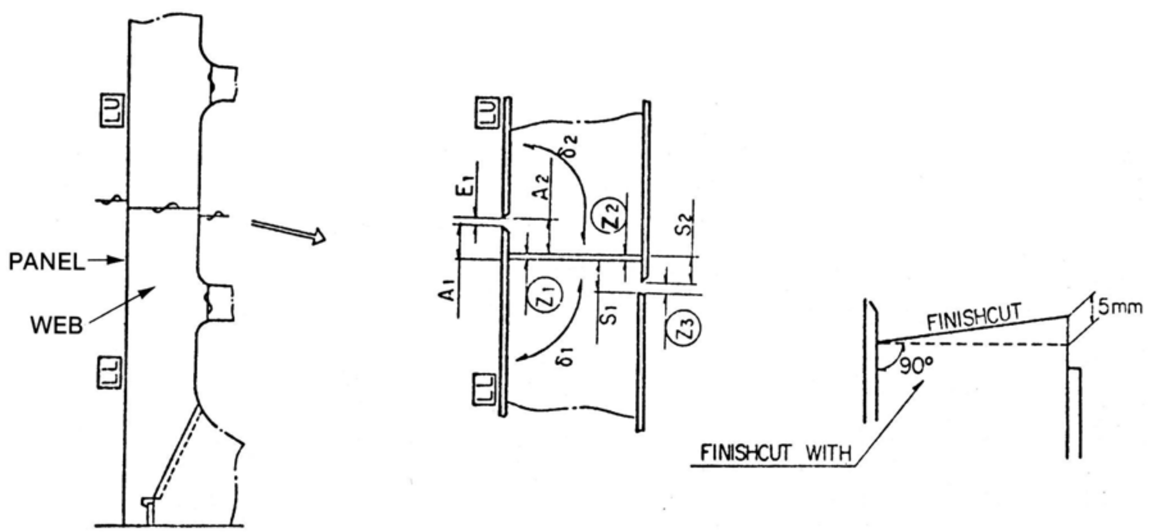
APPENDIX C

EXAMPLES OF VARIATION MERGING EQUATIONS USED BY A/C PLANNERS

I. ERECTION JOINT OF TRANSVERSE WEB FOR A 70,000 DWT TANKER

Assembly Procedure

1. Fit the face plate to the web for the LL block shifted by S_1.
2. Fit the face plate to the web for the LU block shifted by S_2.
3. Fit the web to the panel for the LL block at A_1 from the panel edge, where A_1 = the design dimension + 2 mm.
4. Fit the web to the panel for the LU block at A_2 from the panel edge.



Variation Merging Equations

$$Z_1 = (A_1 + E_1) - A_2$$
$$Z_2 = Z_1 - (\delta_1 + \delta_2) + (Ex_1 + Ex_2)$$
$$Z_3 = Z_2 + (S_1 - S_2)$$

Ex_1 and Ex_2 are inaccuracies due to curved deformation on inclination from vertical during erection which effects accuracy of the web gap Z_2 near the face-plate side. Since it is difficult to obtain measurements of certain dimensions at the erection site, Ex_1 and Ex_2 were calculated from the measured value of Z_2. Z_3 was calculated using Z_2.

ESTIMATED MERGED VARIATION

Dimension	Sample size n	Mean value $\bar{x}$	Variance σ^2	Remarks
δ_1	48	+ 4.8	1.17	Right angle degree of upper end of LL web [After cutting with edge extended 3mm (5mm − 2mm)]
δ_2	56	− 0.3	1.00	Right angle degree of lower end of LL web
S1	48	+ 0.7	1.56	Fitting position of face plate to web (LL)
S2	56	+ 1.5	1.48	Fitting position of face plate to web (LU)
A1	54	+ 1.8	2.32	Fitting position of web frame LL (L) to panel
A2	82	+ 0.6	2.48	Fitting position of LU web frame to panel
E1	101	− 1.6	2.91	Accuracy of seam joint of LL x LU (dimension between reference lines after welding)
Ex1 + Ex2	—	+ 5.2	4.92	
Estimated Gap				
Z1	—	− 0.4	7.71	Estimated back-strip welding 2.5%
Z3	—	− 0.5	17.84	—— do. —— 9 %

ACTUAL MERGED VARIATIONS

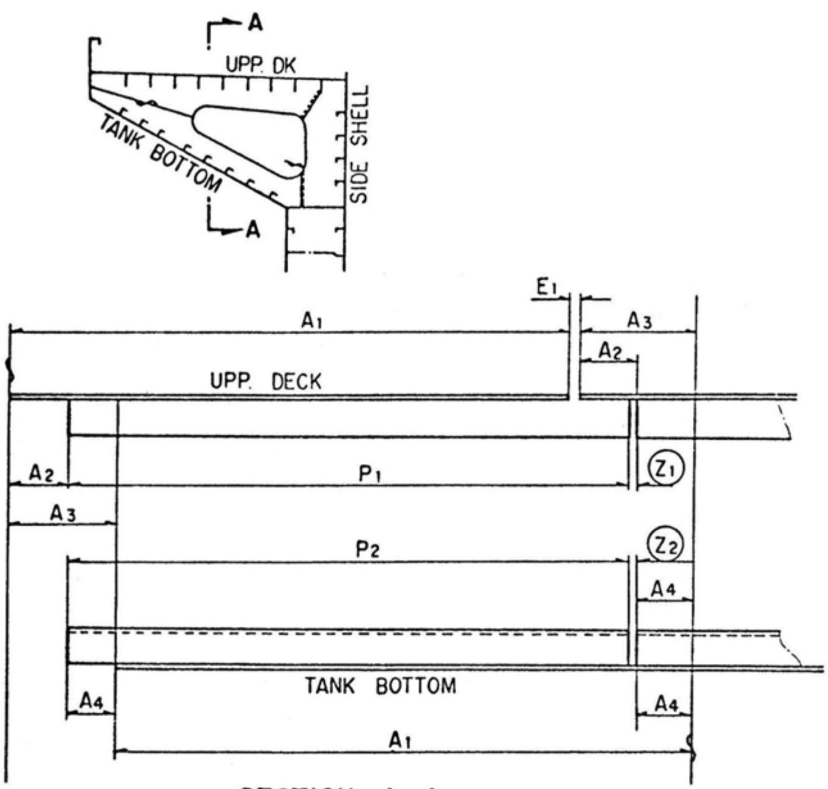
Actual Gap	Sample size n	Mean value $\bar{x}$	Variance σ^2	Confidence intervals* of population variance (confidence level 90%)	Normality test* (significance level 10%)	Actul ratio of back strip
Z1	79	−0.7	8.39	6.63 − 11.25	$\chi_0^2 = 8.50 < \chi^2_{(7, 0.10)} = 12.02$	2.5 %
Z2	79	+0.3	14.80	−	$\chi_0^2 = 11.15 < \chi^2_{(12, 0.10)} = 18.55$	7 %
Z3	61	−0.2	15.30	11.80 − 21.60	$\chi_0^2 = 5.51 < \chi^2_{(7, 0.10)} = 12.02$	6.5 %

*Concepts are addressed in Appendix B and E.

II. ERECTION BUTT OF DECK & BOTTOM LONGITUDINALS OF UPPER WING TANK FOR A 50,000 DWT BULK CARRIER

Assembly Procedure

1. Fit longitudinals on deck and tank-bottom panels maintaining A_2 and A_4 respectively at the aft ends.
2. Provide 3 mm excess and finish cut fwd end of deck panel.
3. Provide some margin at the fwd end of the tank-bottom panel to be cut after the block is set during erection.
4. When joining the tank-bottom block with the deck block, align them by the distance A_3.



SECTION A-A

Variation Merging Equations

$$Z_1 = (A_1 + E_1 + A_2) - (A_2 + P_1)$$
$$Z_2 = (A_1 + E_1 + A_3 - A_4) - (A_3 + P_2 - A_2)$$

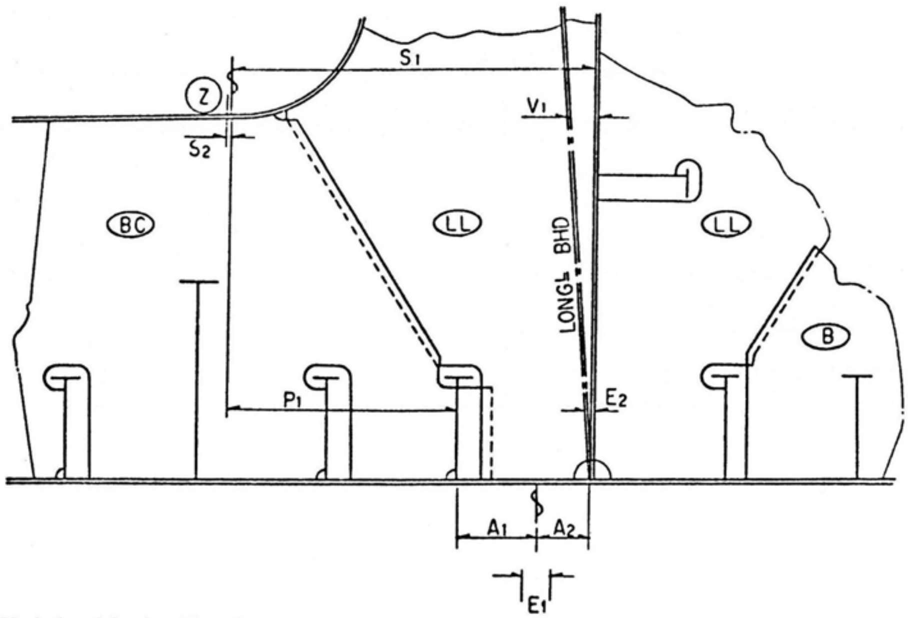
ESTIMATE MERGED VARIATION

Dimension	Sample size n	Mean value $\overline{x}$	Variance σ^2	Remarks
P1	70	−0.4	1.88	Length of longitudinal
P2	68	+3.8	2.25	Length of tank bottom longitudinal (to be cut 3mm. longer than design dimension)
A1	38	+1.3	1.84	Length of upper deck plate
A2	128	+0.1	2.23	Fitting position of deck longitudinal
A3	64	+1.2	6.04	Longitudinal relative position of upper deck panel and tank bottom panel
A4	128	+0.3	4.14	Fitting position of tank bottom longitudinal
E1	42	+0.4	3.24	Accuracy of butt connection of upper deck (dimension between reference lines after welding)
Estimated Gap				
Z1	—	+2.1	11.42	Estimated ration of back-strip welding 20%
Z2	—	−2.3	25.78	—— do. —— 8 %

ACTUAL MERGED VARIATIONS

Actual Gap	Sample size n	Mean value $\overline{x}$	Variance σ^2	Confidence intervals of population variance (confidence level 90%)	Normality test (significance level 10%)	Actul ratio of back strip
Z1	102	2.6	9.16	7.5 − 12.0	$\chi_0^2 = 11.69 < \chi^2_{(9,0.10)} = 14.68$	14%
Z2	82	−1.7	22.60	17.8 − 30.0	$\chi_0^2 = 6.96 < \chi^2_{(6,0.10)} = 10.64$	6%

III. ERECTION JOINT IN FACE PLATE OF TRANSVERSE WEB

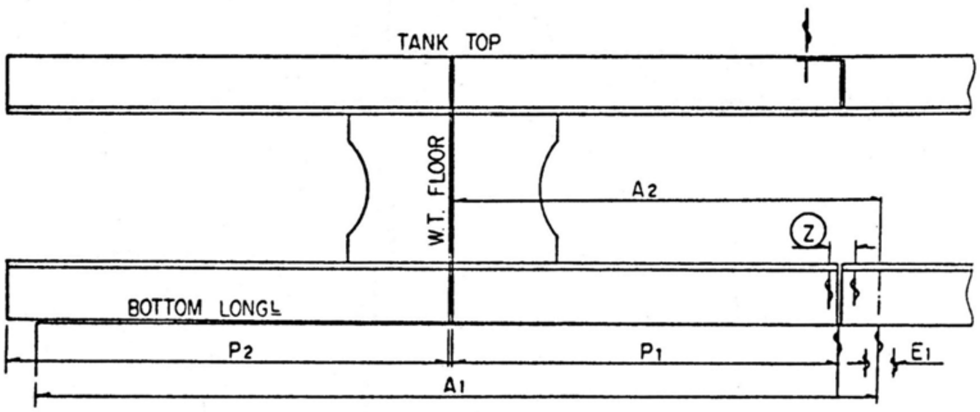


Variation Merging Equation

$$Z = (S_2 + P_1 + A_1 + E_1 + A_2 + E_2) - (S_1 + V_1)$$

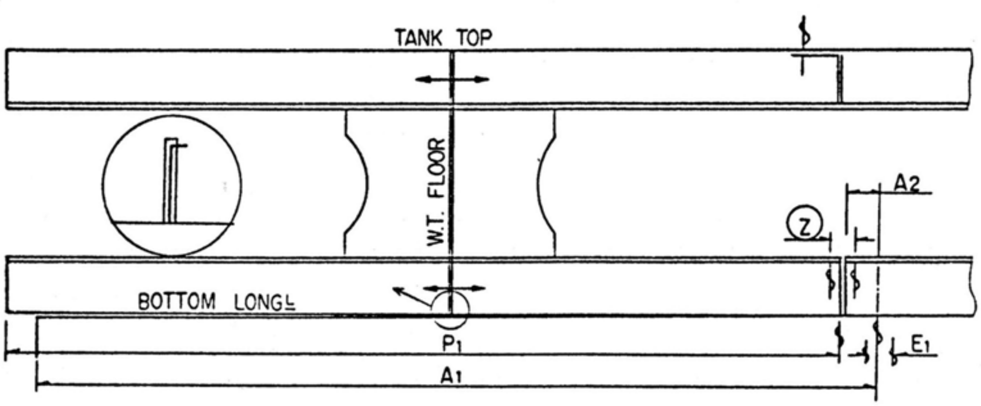
Stage	Process	$\bar{X}$	σ	σ^2	Remarks
Part Fabrication	P_1 (Stop position of Bottom Trans Fc. PL. to web edge)	0	0.9	0.81	
Sub-block Assembly	S_1 (End position of Fc.PL. from L. BHD)	+2	0.8	0.64	Intentionally fit 2 mm longer because of the large variance of Z, 15.30.
	S_2 (Gap of Fc. PL. of Bottom trans)	0	0.8	0.64	
Block Assembly	A_1 (Fitting position of B. long'l)	0	1.4	1.96	Shrinkage by welding of BC x B seams to be investigated.
	A_2 (Marking position of L. BHD)	+2	1.0	1.00	
Erection	V_1 (Deviation of L. BHD)	0	2.0	4.00	
	E_1 (Distance between reference lines)	−2	1.5	2.25	Distance between reference lines after welding (2 mm shrinkage to be investigated).
	E_2 (Installation against L. BHD mark line)	0	2.0	4.00	
Merged Variation	Z	−2	3.9	15.30	Cutting 69% back-strip welding 3.7%

IV. DECREASING THE NUMBER OF PROCESSES BY DESIGN IMPROVEMENT



Variation Merging Equation

$$Z_1 = (A_2 + A_1 - A_2 + E_1) - (P_1 + P_2) = A_1 + E_1 - P_1 - P_2$$



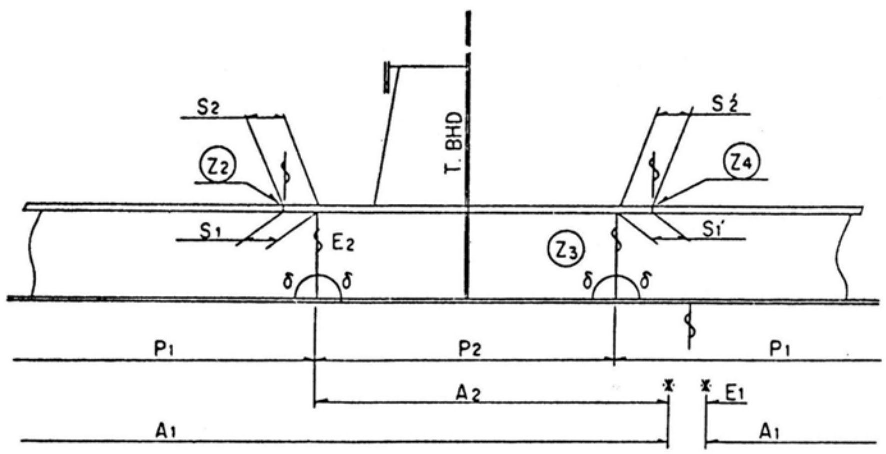
Variation Merging Equation

$$Z_2 = (A_1 + A_3 + E_1) - (A_3 + P_3) = A_1 + E_1 - P_3$$

Z_2 is more advantageous than equation Z, because there are fewer opportunities to generate variations. However, there would be no advantage if the variations of P_1, P_2 and P_3 were small compared to A_1, A_2 and E_1. This type of analysis is used to quantitatively determine the best design details for given production capabilities.

V. DECREASING THE NUMBER OF PROCESSES BY CHANGING THE ASSEMBLY SEQUENCE

The number of processes required for the erection butt-joint in bottom longitudinal shown below is one less than for that illustrated in Figure 3-2 of the basic text. Added processes sometimes increase merged variation at the final process. However, an added process which does not contribute significantly to merged variation can be advantageous. In Figure 3-2, the added process would permit the transverse bulkhead to be set more accurately.



Variation Merging Equations

$$Z_2 = (S_1 - \delta) - (S_2 + \delta) + E_2$$

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

$$Z_4 = (S_1' - \delta) - (S_2' + \delta) + Z_3$$

Stage	Process	$\bar{X}$	σ	σ^2	Remarks
Part Fabrication	P_1 (Length of bottom long'l)	−1	1.0	1.00	Negative $\bar{X}$ means on the average the longitudinals, P_1, are short.
	P_2 (Length of penetration piece)	0	1.0	1.00	
	δ (Accuracy of squareness)	0	0.5	0.25	As shown by deviation of the upper most point of bottom long'l edge.
Sub-block Assembly	S_1 (Gap of Flange PL. of P.)	0	0.8	0.64	
	S_1 (—————— do. ——————)	0	0.8	0.64	
	S_2 (Gap of Flange PL. of Pen Pc.)	0	0.8	0.64	
	S_2 (—————— do. ——————)	0	0.8	0.64	
Block Assembly	A_1 (Length of bottom PL)	+3	1.2	1.44	Shrinkage of main butt to be investigated.
	A_2 (Edge joint of Pen Pc.)	+3	1.2	1.44	
Erection	E_1 (Distance between reference lines after welding)	−2	1.5	2.25	2 mm shrinkage after welding to be investigated.
	E_2 (Butted gap)	+1	1.5	2.25	
Merged Variation	Z_2	+1	2.0	4.00	Positive $\bar{X}$ means a joint gap exists.
	Z_3	+1	3.3	10.89	
	Z_4	+1	3.5	12.25	