S-44 for Dummies

by Pat Sanders (Hydrographic Heretic)

In my travels, I am always confronted by hydrographers who want to know how to determine whether their hydrographic survey data meets the S-44 standards.

What the hell is S-44? The International Hydrographic Organization publishes a document entitled 'IHO Standards for Hydrographic Surveys'. It's referred to as 'S-44', which stands for Special Publication No. 44. You can download the most recent edition (5th Edition, Feb 2008) from their web site: www.iho.int/iho_pubs/standards/S-44_5E.pdf. It's about 36 pages and makes for some interesting reading, provided you are infatuated with statistics. The document provides *minimum standards* to be achieved for different types of hydrographic surveys. It is updated from time to time to reflect new survey techniques and practices. The 1st Edition came out in 1968 and was entitled "Accuracy Standards for Hydrographic Surveys".

How accurate does my survey need to be? You'll see in a bit that all traces of the word 'accuracy' have been expunged from the standard. Likewise, the term 'error' is also being replaced by 'uncertainty'. In their Glossary, the IHO defines accuracy as follows:

> ***Accuracy****: The extent to which a measured or enumerated value agrees with the assumed or accepted value.*

I don't like them using the term 'accepted value'. Just because 9 out of 10 of you say the capital of Nevada is Las Vegas, doesn't mean you are correct. (It's Carson City…) I would suggest a better definition would be:

> ***Accuracy****: The extent to which a measured value agrees with the true value.*

The problem with trying to quantify your survey results based on 'accuracy' is that very few of us have any information on the true depth value. Unless you are fortunate enough to be surveying in a lock chamber which has a perfectly flat bottom at a known depth, you do not have a 'true value' to use to compare your measured depth. Since we cannot determine the accuracy of the measurements, the IHO has migrated to using 'Uncertainty' and 'Confidence Levels'.

What are Uncertainty and Confidence Levels? The IHO defines uncertainty as follows:

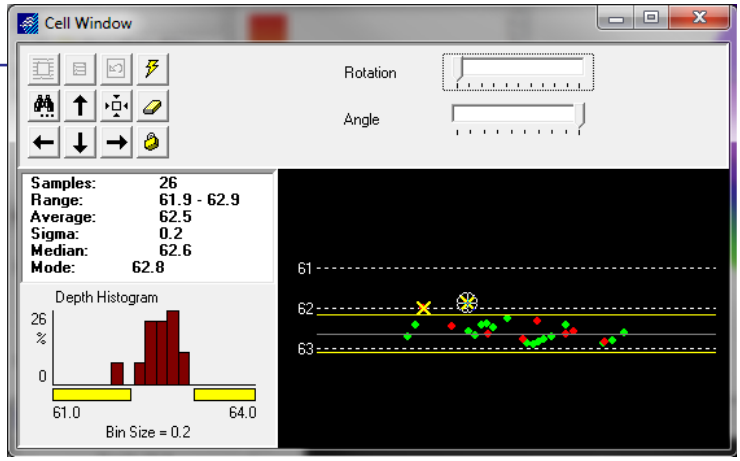
> **Uncertainty***: The interval (about a given value) that will contain the true value of the measurement at a specific confidence level.*

John Taylor in his book 'An Introduction to Error Analysis' notes that uncertainty is '*Based on either limitations of the measuring instruments or from statistical fluctuations in the quantity being measured.*' This will be important later on, as we will see we can try to quantify uncertainty by analyzing the overall error budget of our data collection system ('limitations of the measuring instruments') or by examining the statistical distribution of measured depths ('statistical fluctuations').

> **Confidence Level:** *The probability that the true value of a measurement will lie within the specified uncertainty from the measured value. …the 95% confidence level for 1D quantities (e.g. depth) is defined as 1.96 x standard deviation and the 95% confidence level for 2D quantities (e.g. position) is defined as 2.45 x standard deviation.*

Let's take a look at a couple of examples.

FIGURE 1. *Statistical Distribution of Depths in the HYSWEEP® EDITOR*



The diagram (right) is from the HYPACK® Multibeam Editing program (MBMAX). It shows the statistical distribution of depths for a square-shaped bin. The standard deviation for this group of soundings (Sigma) is calculated at 0.2'.

The 95% confidence level for depths is defined as 1.96 times the standard deviation. For this distribution, it would be computed as 0.4'. This is the 'uncertainty' for all of the depths in the bin. I'm still going to pick one depth to represent the bin when I go to plot the soundings or compute volumes. I might pick a median depth of 62.6 for a dredging project, or the minimum depth of 61.9 for a cartographic map. Both of them share the statistical 'uncertainty' of 0.4'.

FIGURE 2.

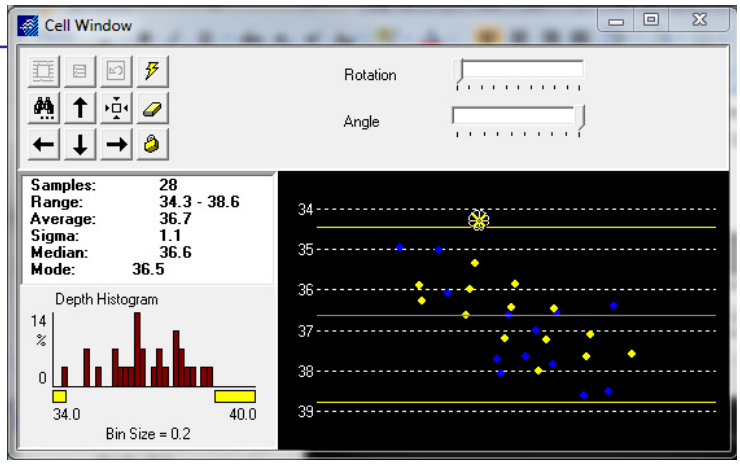


Figure 2 shows the distribution of depths for another 'bin'. In this instance, the standard deviation is computed as 1.1', and the 95% confidence level is 2.2'. Since the uncertainty for this data grouping is much larger than that of the previous example, I am:

- less confident in my measurement
- more uncertain about my measurement

The computation of uncertainty by examining the distribution of depths in a 'bin' can be adversely affected if your 'bin' is located on a side slope. You may have actually 'nailed' every depth and gotten the true depths, but since the depths in the bin are on a side slope, you'll get a lousy standard deviation and an uncertainty value that may not reflect your ability to meet certain standards.

What are the standards? In the S-44 document, the IHO proposes minimum standards for Positioning and for Depths. Some hydrographers are probably familiar with the term TPU (Total Propagated Uncertainty). It is composed of a horizontal component (THU = Total Horizontal Uncertainty) and a vertical component TVU (Total Vertical Uncertainty).

For depths, they sub-divide the minimum standards into four different survey types (or Orders).

- **Special Order**: Areas where under-keel clearance is critical.

- **Order 1A**: Areas shallower than 100 meters where under-keel clearance is less critical but features of concern to surface shipping may exist.
- **Order 1B**: Areas shallower than 100 meters where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.
- **Order 2**: Areas generally deeper than 100 meters where a general description of the sea floor is adequate.

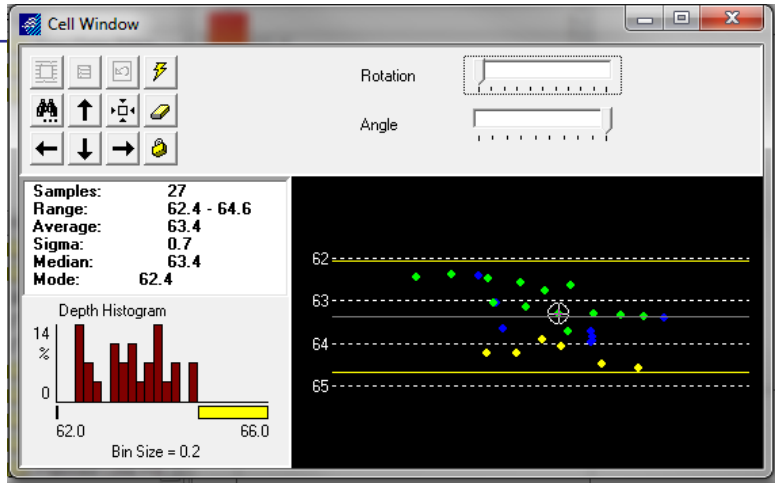
The maximum allowable TVU for each order is specified using the formula $\mathbf{[\ a^2 + (b \times d)^2]^{0.5}}$, with the result in meters. Table 1 in S-44 provides the constants for **a** and **b** for each Order of survey, while **d** equals the measured depth. If I insert the values for **a** and **b** into the formula, I get the following:

- **Special Order**: $[\ 0.06 + (0.0075 \times d)^2]^{0.5}$
- **Order 1A**: $[\ 0.25 + (0.013 \times d)^2]^{0.5}$
- **Order 1B**: $[\ 0.25 + (0.013 \times d)^2]^{0.5}$
- **Order 2**: $[\ 1.00 + (0.023 \times d)^2]^{0.5}$

So, for a couple of different depths, your TVU would have to be less than the following for each of the four orders:

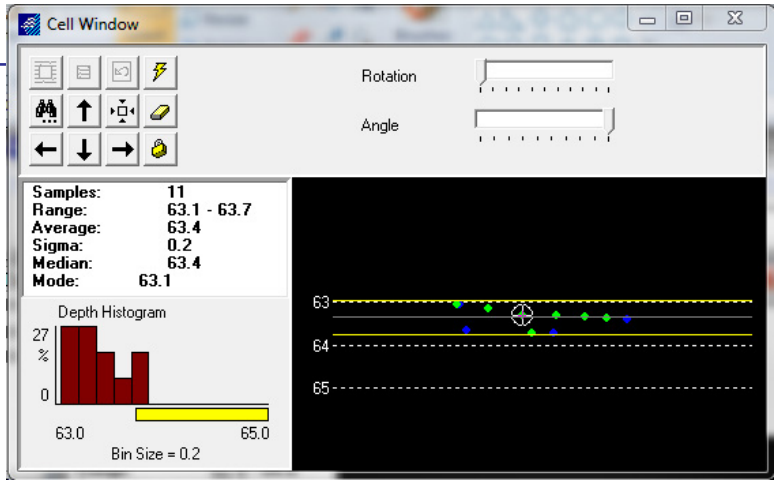
Depth	Special Order	Order 1A	Order 1B	Order 2
5m (16.4')	0.25m (0.8')	0.50m (1.6')	0.50m (1.6')	1.01m (3.3')
10m (32.8')	0.26m (0.8')	0.52m (1.7')	0.52m (1.7')	1.03m (3.4')
20m (65.6')	0.29m (1.0')	0.56m (1.8)	0.56m (1.8')	1.10m (3.6')
50m (164.0')	0.49m (1.6')	0.82m (2.7')	0.82m (2.7')	1.52m (5.0')

FIGURE 3.



In Figure 3, the median depth is 63.4' (just under 20m). The standard deviation for the depth values is 0.7'. The 95% confidence level would be 1.96 times this value, or 1.4'. Our TVU would meet the requirements for Orders 1A, 1B, and 2, but not for Special Order.

FIGURE 4. *Data Points Within 0.5ft.of the Median*



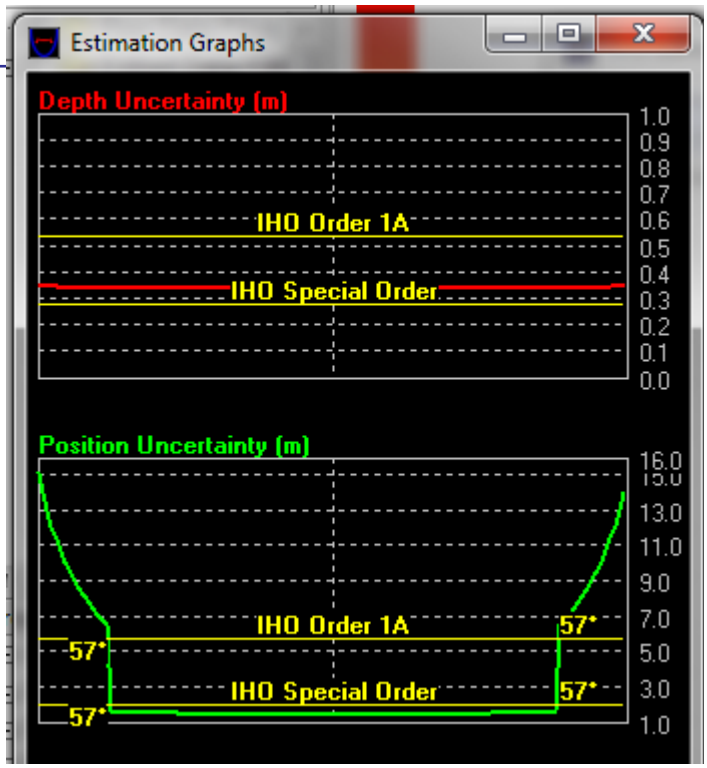
If we remove some 'outliers' by eliminating any data points greater than 0.5' above or below the median value and then look at the statistics, the Standard Deviation falls to 0.2' and the 95% confidence level is 0.4'.

We can now claim that our survey data meets the specification for Special Order! ….or can we?

Is it fair to remove extraneous data points by automated or manual filtering and then apply your statistical tests? I would venture the answer should be '**No!**'. Anyone can meet a statistical requirement by deleting points about the median until the 95% confidence level falls below the necessary standard. Yet, it's a method used by some multibeam manufacturers to support their claims that their systems can meet IHO requirements at ever widening swaths.

How do you compute THU and TVU from error budgets?: If we can determine the errors inherent in each piece of equipment and how those errors are inter-related, we can make calculations that will estimate the THU and TVU.

FIGURE 5. *Total Propagated Uncertainty (TPU) Graphs*



For example, how precisely can we measure the roll of the vessel? Our patch test might show that over time, we have determined the roll offset with a 95% confidence value of +/- 0.10 degrees. On our nadir beams, being off by 0.1 degree won't have much of an effect on the final depth. On our outside beams, small errors in the roll measurement can result in large errors in the final depth. The uncertainty that we compute, both TVU and THU is going to be dependent upon the beam angle.

THU and TVU can be computed as predictions based on an assumed depth, or can be computed for real

time data. The advantage of the real time data is that several estimates used in the prediction can be replaced by actual data.

Looking at the screen capture (Figure 5), based on our inputs, our survey would not meet the IHO TVU requirement for Special Order, but would meet the requirement for Order 1A. (HYPACK® still uses the term Depth Uncertainty, which is the same as TVU.) The Position Uncertainty (THU) shows that we would only meet either standard out to a beam angle of 57 degrees from nadir.

What happens if your TVU computed in predicted and/or real time mode based on the error budgets meets the requirement, but your computation of TVU based on the statistical distribution of binned depths does not?: That's a good question. S-44 doesn't address this. I suppose you could claim that based on one of the tests, you have met the IHO requirement (and keep quiet about the other test….).

There are a lot of parameters that need to be entered in order to compute the TVU based on error budgets. Which items are most important?: Well, here goes nothing…

- **Pulse length** of the multibeam system seems to have a large effect. The longer the pulse length, the greater your uncertainty.
- **Depth of Bottom** also has an effect. The deeper you are sounding, the greater the overall uncertainty. However, the Maximum allowable TVU also increases based on the depth. The two items don't balance out exactly, so you'll just have to experiment to see the result.
- **Water Level Uncertainty:** How accurately can you measure the tide at your tide monitoring station? This has a direct effect on the TVU. Most surveyors don't have any idea of how accurately they can measure the tide.
- **Spatial Tide Prediction Uncertainty:** How accurately can you determine the tide corrections in your survey area based on a tide monitoring station located outside your survey area? This has a direct effect on the TVU, but most surveyors have absolutely no idea of what value to enter.
- **Draft, Squat and Loading Uncertainties:** How accurately can you determine the static draft, dynamic draft and change in draft due to different loading conditions? Each of these has a direct effect on the TVU, but very few surveyors have any idea of what values to enter.
- **Fixed Heave Uncertainty:** What's the fixed component of your ability to precisely measure the heave? This one really makes the TVU graph go up/down!
- **Roll Sensor and Roll Offset Uncertainty:** Based on your history of your patch tests, how precisely can you determine the roll offset? As you go from 0.05 degree to 0.1 degree to 0.2 degrees, you will see a drastic reduction in the beam angles that will meet the standard.

There seems to be a lot of room for interpretation (or mischief).: I agree. In my confidential talks with most hydrographers, if they don't understand a value, or don't have any information to support a value, they will just either use default values or make adjustments until they have demonstrated they meet the TVU requirement at some very wide beam angles. It's one of the reasons I'm not a big supporter of using TVU and THU to reject sounding data. If the parameters are not correctly set, it's just a **bogus** computation.

Well, if you would let me summarize:

- **The statistical method of computing TVU is unreliable on side slopes and can be tampered with by filtering data before running the tests.**
- **The error budget method of computing TVU is dependent upon the hydrographers correctly entering parameters, many of which they have no clue on what to enter.**

Ouch. That's pretty cynical. TVU and THU should be just one tool in the hydrographer's tool box. It's an important tool, but I would rather rely upon statistical evidence, such as the HYPACK® Performance Test for Multibeam Systems that compute the actual repeatability (95% confidence) and depth bias versus beam angle.

What's a Performance Test?: Maybe I'll rant about that in the next newsletter…..