The quality control cycle in the age of electronic chart production, contracted work and ISO certification

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Abstract

The earlier models of QC in hydrographic production were designed for and suited to the organizational structure and products of their time. All production of a one-item (paper) product line was carried out in-house (except for an occasional closely supervised contract), standards had matured over a number of iterations, all steps in the process were clearly visible, and QC consisted of a number of post-stage inspections to ensure that the product conformed to the standards. Recent developments have changed all that. Like most Hydrographic Offices, the CHS now has a triple-item product line (paper, raster, vector) for which standards are immature, varying amounts of production are contracted out, computer assisted processes are applied to increasing levels of complexity, and identifying stages at which to inspect the in-production work is not easy.

In an attempt to deal with these forces, a number of HOs have launched ISO Certification initiatives. Included among the many benefits of undergoing such an exercise is the opportunity to examine the QC process and its role in the evolving production cycle. The first stage is normally to document and measure the actual process as it is carried out within the organization; once that is clearly understood, it may be possible to formulate recommendations for improving and streamlining the process.

This paper presents some examples of the ENC production process and how it is Quality Controlled within CHS at present. It goes on to suggest how this can be made more efficient. The work is of interest beyond the CHS, since all HOs have a shared interest in conforming to similar professional practices, particularly in the area of Quality Control.

1. Quality and hydrographic charts - introduction

Hydrographers have been concerned with the quality of the charts they produce for mariners since hydrography's earliest beginnings. Indeed, much of the exploration era history of hydrography was totally concerned with improving quality through the completion or 'filling in the white spaces" on the chart. An over-riding passion was and is the desire to find every shoal that could possibly impact shipping, and no chart can be considered to have any acceptable amount of quality unless it portrays all the shoals. For many years, hydrography was protected or insulated or distanced from quality issues by two powerful buffers. One was that the accuracies (uncertainties) attainable by hydrographic surveyors were an order of magnitude or more better than any that a mariner could aspire to. The second was that Hydrographic Offices (HOs) controlled the scale of the printed chart, and could through this one device simultaneously control the magnitude of any errors (area of uncertainty) that might appear in the data, and control the accuracy to which the mariner could use that same data.

All that has changed. Of great concern is the fact that the changes may not be fully understood and that consequently HO procedures may not have changed to suit. Quality Control (QC) procedures that evolved during the paper chart age may no longer be suitable/applicable/effective in the digital age, yet the approach that evolved during the paper age is, to some extent, still being applied.

The first great change that has occurred arose from the digital revolution. Very powerful, easily operated and reliably accurate instrumentation is available to all seafarers. For example, ships' officers are as capable of operating Global Positioning System (GPS) receivers as are hydrographers, and can obtain positions that are more accurate than the positions of the charted depths over which they are sailing, if those depths were collected but a few years ago. The second buffer was removed by the introduction of the Electronic Navigation Chart (ENC). Although ENC committees initially struggled to prevent it, and more recently to at least warn against it, ENC users can and do expand the horizontal scale of the chart until it produces an image that suits their eye. The protection once afforded by the paper chart's carefully selected scale is gone.

In time sequence with these changes, HO s have greatly changed the way they perform their tasks. Changes to positioning, sounding and data logging instrumentation driven by the digital revolution have been astounding, exciting, wonderful and even a little frightening. Nevertheless, these changes are more easily understood than the most significant change brought on by the digital revolution, the switch to the production of spatial objects. No longer is the final outcome of the labours of the many specialists within hydrography a collection of inked marks on a sheet of paper, it is now a very powerful linked assemblage of spatial objects arranged in a digital file. Like all powerful tools, it can multiply the results and the usage of itself, and like all powerful tools, it can be misused with the consequences of so doing that can be disastrous.

The authors believe that these factors conspire to require, in fact insist, that HOs develop appropriately even more powerful QC procedures which utilize digital tools, and to develop experienced and talented workers, to ensure that products are of a sufficiently high quality that they protect both user and producer.

This paper presents some of the experience the CHS has in developing a new approach to QC, and points out some of the challenges that lie ahead.

2. The roots of hydrographic QC - The paper chart production process

Conceptually, the paper chart production process had strong affinities to Henry Ford's assembly line. Components of the final product were manufactured in-house or else brought in (e.g. Ford built car bodies and brought in tires, surveys were performed by HO staff, while topography was obtained from another agency). The in-house elements were checked by various means, while the brought in material was often accepted as obtained. The numerous components were assembled and the final product was inspected on completion (e.g. surveys, shoreline, topography, aids, nomenclature, magnetics) were compiled and drafted into charts that were inspected during assembly, and inspected by some "higher' or "final" authority on completion just before printing. Problems detected at this stage were resolved, either through replacing the defective portions, or deciding that it was not important enough to delay printing and would be corrected at the next edition.

The final inspection stage crystallized what was really at issue. It was and is a stage that absorbed a great deal of energy in the paper chart era, and which remains to be dealt with in the age of ENCs. Essentially, some components of a chart are the results of technical operations and can be quantified, while others are required by the presentational or cartographic visualization and are judgmental. These latter components soak up energy and debate, and getting an HO to agree internally how it wishes to interpret the rules of production, so that a standardized product is issued is indeed time consuming and difficult.

3. New hydrography The electronic production process

HO s began the long and slow process of introducing themselves to the digital world and the digital world to hydrography through functions and processes that were clearly mathematical, like the drawing of projection grids and lattices. Over time, digital methods that replicated manual techniques emerged. Despite the euphoria that surrounded them, in many ways these did not represent a paradigm shift, but an early attempt to adopt a new technology to an existing process. QC was essentially unchanged, and there was no attempt to modify procedures. The main struggle was how to use digital tools to speed-up the existing manual processes. Improving quality may have been an objective, but it was subsidiary. There were arguments that digital processes were more objective, for tasks such as contouring sounding data, for example, but this proved to be a difficult argument to bring to any conclusion.

Early Electronic Charts used the same digital file as that used to create the paper chart image. However, with the introduction of S-57 ENCs, the digital file does not merely have to produce an image that appears correct when printed, the file structure has to contain several more types of information that must be correct in order for the ENC to perform its tasks, one of which is to portray an image. Consequently, the QC process now must ensure that these greater amounts of information are thoroughly checked. Mechanisms to do this, including tools like self- checking scripts are discussed in later sections of this paper.

As an aside, one branch of the digital revolution that must be mentioned is digital plotting and printing, often called Print on Demand (POD), which occupies a transition point between full analogue and true digital production. Once digital cartographic production processes had evolved to the point where a complete digital chart file could be produced, digital printing, as opposed to lithographic, could be envisioned. Early efforts were hampered by the size of the printer available, as well as the quality of the paper that the chart could be printed on. These problems have now been largely resolved. These problems also distracted investigators somewhat from the uncomfortable finding that what was in the digital file, was not always what was printed on the printer. Occasionally some items would be omitted. Although this was rare, it did raise QC concerns and perhaps indicated that *every* copy produced by POD would have to inspected as it was printed, meaning that the task of printing could not be entrusted to an un-trained person, and that the demands on QC would increase as POD is implemented.

4. The Components of Traditional QC

<u>a) Education And Training</u>

Although there are usually formal QC groups within HOs, it is important to remember that organizations have at their disposal a number of mechanisms or tools that combine to in fact define the quality of their finished products. The first and most important of these is training: this includes the formal education and training that staff has before joining, combined with the on-the-job training and classroom sessions that the organization offers. Through its daily actions, and in particular those of its senior management, each organization makes statements of its inherent beliefs about what the quality of its products should be, and this translates to training in a profound manner.

b) Planning and decision making

Planning and decision making plays a role in quality control. The decision to chart a harbour at a certain scale, for instance, defines the level of accuracy that is expected within that chart.

c) Survey design or data gathering strategy

Survey design or data gathering strategy, for whatever type of data, plays a major role in QC. Sounding surveys, for instance, can introduce redundancy through the appropriate use of check lines, and thereby enhance the QC of surveys. Timing and placement of temporary tide gauges can greatly impact the quality of data generated by allowing for local survey area adjustments.

d) Standards

Standards, be they the ones that specify a product to be created, for performance of the product once created, for the procedures to be used in its creation, for the data it is based on, or for its accuracy, in fact the entire gamut of hydrographic activities, provide another suite of tools for the QC toolkit. In hydrography, we are fortunate to have international standards that all member states contribute to, and that national standards can support and in turn be supported by. (IHO, IMO, NMEA(National Marine Electronics Association))

e) Manuals

Many HOs supplement their standards with Manuals, sometimes called Standing Orders. Generally, these are sets of instructions that relate what hydrographic staff will have learned during their formal education to the specific tasks of the organization. They often will also form the basis for the in-house training that organizations conduct, and may be given to contractors as part of the specifications of a contract. They can codify the organization's expectations about the quality of its products, and describe the activities that should be undertaken to achieve that quality. If they suffer a weakness, it is usually that they do not keep pace with development, especially during the last few years. Some critics allege that they cannot anticipate every situation, while their defenders respond that they are not intended to….

f) Retroactive Quality Evaluation.

Most HOs have been collecting data for many years, some for more than a century. The ocean is so vast and survey vessels so slow, that all data must be kept and considered until it is replaced and disproved by new data sets. This means that a product constructed today may be using data that were collected to earlier standards, and which has to be somehow incorporated into the new product. This may be made even more difficult due to the qualitative nature of some hydrographic specifications; for example, how is an older survey with "all shoals examined" to be compared with a newer one in which there is no notice remarked about shoals. There have been a number of mechanisms used to incorporate older data and they include some form of QC, which in this context we term retroactive quality evaluation.

g) ISO

A number of HOs are adopting the International Organization for Standardization (ISO) approach to *managing* what an organization does to ensure that it is meeting its quality goals, which have ideally been based on customer requirements. ISO in and of itself does not directly provide performance or other types of standards: rather it specifies how and when existing standards are to be applied. But the circle must be completed: the standards invoked must be based on what the customer requires, no more and no less, or a basic reason for entering the ISO process has been violated. This may require the re-writing of some existing standards so that they conform to, and respond to, customer demands. However, HOs are immediately struck by a paradox: for many years, hydrographic charts were built to suit as wide a range of users as possible, albeit that navigation was paramount. Which user requirements should the new standards seek to meet, those of the commercial mariner, of the scientific community of users, of the pleasure boater, or of all of our customers at once? Clearly, how the new standards are written will depend on how this question is answered.

h) Professional Practice

These tools are not applied indiscriminately. The codes of professional practice, to say nothing of product liability laws, dictate that all HOs operate in approximately the same way, that is, they apply approximately the same QC tools at approximately the same intensity at all levels.

i) Inspection

All HOs inspect or assess their products at various stages of production and in a number of ways. New information is checked against older material. Staff self check their own work as they proceed. Sometimes they exchange projects and do a peer check on another employees project. All supervisory staff perform a certain amount and level of inspection as they check on the progress of an employees project. Specialists might check particular items, floating aids for example, off-line. For paper charts, repro specialists check repro material and finally, for paper charts, hand amendment workers perform a check on the print quality.

In most organizations, all products undergo a formal inspection and sign off at some stages. Particular, and perhaps undue, emphasis often has been placed on the final inspection before printing, and this has sometimes created the erroneous impression that “QC” comprises this final inspection. This section’s elaboration of the many different components of QC indicates the fallacy of this impression: QC must take place at *all* stages of production.

5. A Model for QC in the digital era

What should QC consist of in the age of electronic chart production, contracted work and ISO certification? How do the quality control mechanisms of education and training, planning and decision making, data gathering strategy, standards, manuals, inspection, and retroactive quality evaluation apply, if in fact they still apply at all? The answer must incorporate the technological impacts of spatial objects, true scale-less-ness of the final product, and almost perfect positioning. Wells, 1999, has taken a significant step towards answering this question for the particular case of the measurements taken during hydrographic surveys: we attempt below to expand his model to encompass all of hydrographic production. Wells couches his answer in terms of "uncertainty management", that is, given that all measurements have uncertainties associated with them, and that as measurements are combined to make hydrographic products, so too are the uncertainties combined. QC, then, consists of first determining whether any element of a product exceeds the uncertainty permitted, and secondly whether the combination of elements within a product exceeds the uncertainty permitted, and these two may require different approaches.

Table 1. Steps in quality control for a single stage of hydrographic production (sounding survey as an example)

Step 1	Production Action	**ESTABLISH THE SIZE OF THE CONFIDENCE REGION REQUIRED**
	QC Mechanism	b) Planning and decision making c) data gathering strategy, g) retroactive quality evaluation
Step 2	Production Action	**USE A MEASUREMENT SYSTEM CAPABLE OF ACHIEVING REQUIRED CONFIDENCE REGION**
	QC Mechanism	c) data gathering strategy, d) Standards e) Manuals f) inspect or assess
Step 3	Production Action	**ASSESS THE UNCERTAINTIES ACHIEVED**
	QC Mechanism	c) data gathering strategy, f) inspect or assess
Step 4	Production Action	**PRESENT UNCERTAINTIES IN AN EASILY-UNDERSTOOD WAY**
	QC Mechanism	d) Standards

To manage the uncertainties in a standard hydrographic survey, for example, the first step as shown in Table 1, is to establish the size of the confidence region required. These must be appropriate to the use to which the data are likely to be put, so that decisions based on that data, such as following a certain navigation route, can be made with a known level of confidence. While the QC mechanisms employed are clearly Planning and Decision-Making, Data Gathering Strategy and Retroactive Quality Evaluation, it also involves Standards. To some extent, Edition 3 of SP 44 (IHO, 1987) embodied this concept by requiring higher accuracies in water less than 30m, indicating that the required confidence region was smaller in waters where vessels were likely to run aground. Edition 4 (IHO, 1998) expands this into four Orders of survey uncertainty, Special Order, for instance, applying to "specific critical areas with minimum under keel clearance and where bottom characteristics are potentially hazardous to vessels". Of course, surveying to a chosen Order requires using a measurement system (e.g. multibeam equipment, operating procedures, and data cleaning methods) which are capable of achieving this required confidence region. Some standards exist to help determine this. For instance, positioning is covered in the RTCM and NMEA standards for DGPS and although no international standard has yet been developed to deal with uncertainty management for multibeam sonars themselves, individual HOs are preparing their own. Trained personnel, using manuals must deploy the chosen measurement system according to a plan. Inspection at the survey stage will consist of assessing the confidence region actually achieved, after data cleaning, and determining whether the survey meets the requirements, or meets some lower Order, and labeling the survey as achieving that Order. For each survey, the results of these analyses, i.e. the size of the uncertainties, become an important part of the results and must be attached to the survey in such a way as to be accessible at all later stages. Wells, 1999, also insists that the uncertainties (or confidence regions) must be presented in an easily-understood way, a point we return to later.

The reasoning applied in Wells' model can be applied to the many other types of data other than soundings that form part of the hydrographic data set; aids, natural features, cultural features, landmarks, aids, shoreline, tides and currents, wrecks, offshore installations, tracks and routes, areas and limits. This would result, in the traditional approach to chart production at least, in every item of measured data that can be included on a hydrographic chart having its uncertainty expressed as a confidence region. Each would have its own 'file', with its own confidence regions determined and associated. The issue then becomes one of deciding how these disparate files are to be combined into a hydrographic product. Table 2 shows a very general model of this process. Unfortunately, this is not a question with easy answers, and one that generates some controversy as HOs struggle for resolution. The next section outlines the issue and some approaches that are being pursued.

Table 2. Steps in quality control for the production of a complete hydrographic chart.

Step 1	Production Action	**ESTABLISH THE SIZE OF THE CONFIDENCE REGION REQUIRED**
	QC Mechanism	b) Planning and decision making
Step 2	Production Action	**ASSEMBLE THE DATA THAT WILL BE USED IN PRODUCTION OF THE CHART**
	QC Mechanism	c) data gathering strategy, d) Standards e) Manuals i) inspect or assess
Step 3	Production Action	**ASSESS THE UNCERTAINTIES ACHIEVED FROM COMBINING THE VARIOUS DATA SOURCES**
	QC Mechanism	f) Retroactive Quality Evaluation. i) inspect or assess
Step 4	Production Action	**PRESENT UNCERTAINTIES IN AN EASILY-UNDERSTOOD WAY**
	QC Mechanism	d) Standards

5.1 Q C issues when combining different types of data, each with their own assessed uncertainty

All the components of QC listed in Section 4 will continue in place, and will be pursued with due diligence. They will also have to be expanded to address the following:

5.1.1. Consistency within a single data type.

One major and as yet unresolved issue is defining exactly what the uncertainties apply to. For a sounding survey, for example, it is possible to a) calculate a single uncertainty level for the entire survey, or to b) break it into smaller areas and assign an uncertainty value to each of them, or c) break it even further and give every individual sounding an uncertainty. Practice across HOs does not appear to be uniform on this, yet the answer impacts every subsequent stage of production.

5.1.2. Data integration in overlapping areas

Commonly, data collected in the field overlaps data of the same type collected in previous years. In fact, some Standards insist that they must do so, and Planning takes this into account. In the overlapped area, are data combined, and if so, how are data combined, and what uncertainty is to be applied to the resulting data set? Sometimes a quality decision is made that the older data will be totally replaced by the new, in which case no integration is required. Otherwise, what can be done depends on which approach was taken in Point 5.1.1. If 5.1.1a) is used and a single uncertainty calculated for the entire survey, then it is highly unlikely that the older data will have a similar uncertainty and will have to rejected. On the other hand, if 5.1.1b) is used and the survey data are broken into smaller areas, it is much more likely that overlapping areas with appropriate uncertainty can be found. If only one factor contributed to the uncertainty value, a single linear measurement say, then comparison would be easy, but hydrographic data usually have at least three dimensions. This means that their uncertainty is determined from a combination of elements. It is possible to arrive at the same numerical uncertainty value through different combinations: for instance, tight position and sloppy depth might give same uncertainty as sloppy position and tight depth. However, if these two were plotted together, we might find that some lay on top of one another. Suppose that the two areas being compared are found to have different levels of uncertainty: what action can be taken? In other words, what uncertainty should the combined area have? The poorer data cannot be brought up to the higher level, and it would wasteful to degrade the better level data. How to combine the two? This is avoided if point 5.1.1c) of giving every sounding an uncertainty was taken, and uncertainty calculated for each individual data point. In that case, combining two different surveys is simply a matter of overlaying them. Users of the combined data set can select data points according to criteria that can include uncertainty.

5.1.3. How the uncertainties from different types of data accumulate

At a higher level of complexity than two sets of data of the same type, data of many different types are used in constructing a chart. For example, consider a buoy and some soundings. Each has been through one variant of the process above, and each has an uncertainty assigned to it. It is reasonable to suppose that the uncertainty of the combined data set (sounding and aid) is some function of the uncertainty of the individual data sets, but how do they accumulate to arrive at a new value? Although the buoy will not have a depth uncertainty (z), both will have a positional uncertainty (x and y), and what if the positional uncertainties are not the same? How to deal with the fact that the soundings, say, are not positioned as well as the buoy is? Does the combined data set get assigned the greater or the lesser uncertainty, or something in between?

5.1.4. How to display the uncertainties to the users

While the previous questions are difficult and not as yet all resolved, the issue of how to display resulting uncertainty is if anything even further from being resolved. (For clarity, this item is described here as if it were separate and independent, but in fact it is deeply entwined with the preceding factors.) To attempt resolve this issue, the XIIth International Hydrographic Conference (IHC) held in May, 1987, instructed the Committee on ECDIS (COE) "…to set up a working group on the establishment of criteria against which the quality of data used in charting can be codified in order that its reliability can be indicated to the user". A 1995 paper produced by the group so formed proposed the concept of "Zones of Confidence" (ZOC) as a solution. Despite lingering debate, the concept of using ZOCs for the encoding of quality information in S-57, Transfer Standard for Digital Hydrographic Data, was adopted in 1996. S-57 now includes a mandatory attribute (CATZOC) of the meta object M-QUAL which defines the quality of bathymetric data by area. Johnson, 1997, claims that ZOCs provide "a simple and logical means of classifying all bathymetric data and displaying to the mariner the confidence the national charting authority places in it. " S-57 ZOCs classify soundings into six categories of zones to be presented to the mariner, while S-44 classifies sounding surveys into 4 Orders: these are not the same, and some HOs have suggested it is un-necessary to have both. The issue of how these Zones are to be presented to the mariner on either ENC or paper, has yet to be resolved. However, ZOCs are another item to which QC will have to be applied.

While it is understandable that HOs have spent energy debating the merits or otherwise of ZOCs, it has to be underlined that to date, ZOCs apply only to depths, and depths form only a portion of a chart. A chart is made up of a combination of data of many different types, and a mechanism for determining the uncertainty of the complete chart needs to be developed.

6. The role of QC in the age of spatial objects

<u>Individual spatial objects</u>

Hydrography has joined the other Geomatics disciplines in advancing closer towards the true digital era through the introduction of spatial objects. In the digital world, it is possible to describe a feature more completely than was possible on an analogue image, and a great deal of information is stored with each spatial object. It is now no longer sufficient to say that something is somewhere: we now say where that something is and what it is. For hydrographic use, object are identified by a six-character acronym assigned to each object class as defined by the *S-57 Object catalogue (S-57 Appendix A, Chapter 1)*. The CHS uses a subset of an internationally agreed upon set of *object acronyms*. The "Table of Objects, Attribute Codes, Attribute Values and Geometric Primitives" in the Coding Guide in the *S-57 ENC Product Specification and Coding Guide* (PSCG) is organized alphabetically according to object acronyms.

There are several contexts or models that can be applied to produce a framework for QC in the era of spatial objects. One of the more useful, and one that illustrates the newness of this field, is the Table of Contents of a report by the International Cartographic Association Commission on Spatial Data Quality (Guptill and Morrison, 1995). This collection of papers demonstrates that the following elements constitute the uncertainties that must be verified for every spatial object:

a) its lineage or history
b) its positional accuracy
c) its attribute accuracy
d) its completeness
e) its logical consistency
f) its semantic accuracy or the meaning it conveys
g) its timeliness.

Clearly determining the uncertainty associated with these *each* of these diverse elements is more complicated than the process of determining the uncertainty of individual measurements, although doing so is included.

Collections of spatial objects

Collections of spatial objects, be they files or complete data bases, must be checked for the relationships between the spatial objects to ensure that there are no contradictions or inconsistencies. Every HO must ensure that all these elements are accounted for in the quality processes it installs, and devising an over-reaching strategy as well as a detailed approach is a major challenge.

7. The Components of Digital QC

Having seen how the entire hydrographic production process has been impacted by the adoption of digital techniques, including the introduction of spatial objects, we can now return to the mechanisms of QC and see how they are impacted.

a) Education And Training

Progress has been rapid enough in the last dozen years to warrant the term revolutionary. The virtually universal adoption of GPS, the arrival of the EC, the digital revolution, S57 and spatial objects, ISO, are all items that did not exist or where only dimly conceived of until very recently. QC processes have not kept pace, in part because hydrographic staff have not been able to absorb and react to all these developments. A QC strategy must include a large training and education component, which must include major upgrades for existing personnel, many of who received the bulk of their formal training prior to these changes. Training must emphasis the importance of determining uncertainty and associating it with every measurement at each stage of the production process.

b) Planning and decision making

With new standards, notably S44 and the ZOC concept of S-57, planning is even more a part of QC than ever before. Planning for data collection must encompass the final products to be made from the data, since decisions made about uncertainty at the planning stage will be carried with the data throughout its life. Perhaps most important, planning must change its fundamental beliefs to appreciate that survey activities now collect spatial objects, not simple measurements, and the implications of that must be thought through thoroughly.

At a higher level, management decisions about whether or when to adopt a certain process or standard must be made in full cognizance that most modern standards include an explicit or implied uncertainty and that these will have implications throughout the production cycle,

c) Survey design or data gathering strategy

Survey design has long included redundancy as a self-checking means of minimizing uncertainty. This must continue, and the assessment of the uncertainty actually achieved must be included in the survey plans.

Not all data gathered by HOs is data that was collected by hydrographers. Different agencies might supply shoreline, or aids, or traffic separation schemes, for instance. And some data is not collected by an agency: in remote areas, passing mariners continue to provide valuable observations. All these types of data must be assessed for uncertainty and the HOs data gathering strategy must include not only gathering this data, but assessing it as well. Since for some of the data, it will be difficult or even impossible to assess uncertainty, the strategy must include provision for what to do in these cases.

d) Standards

In the CHS currently Digital Chart File Standards (DCFS), and S-57 ENC Product Specification and Coding Guide (PSCG) are the standards used. Most standards already contain, either expressly stated or embedded within some rules, an uncertainty level to be achieved. It would be beneficial if these were made more explicit. There is also a need to examine existing standards as an entire suite to determine whether they contain any contradictions. Finally, many standards need to be updated to include the requirements imposed by spatial objects

e) Manuals

In this digital age, it is often difficult to cover every possible scenario that can be encountered in a digital file, especially in a static manual. Also, the rules or standards are often left purposely vague, so as not to be too constricting, and so, are open to varying degrees of interpretations, which then make it difficult to apply a standard across the board for all ENC products.

f) Retroactive Quality Evaluation.

Because data collection is costly and time consuming, and because the areas to be surveyed are so large in relationship to the resources available, many hydrographic products will be forced to continue to use older data for some time into the future. Hare and Monahan, 1993, have demonstrated that it is possible to assess the uncertainty in older data, and this must be done for older data that are to be incorporated into new products: indeed, it will have to be done to comply with S-57 ZOCs. The process is not trivial, and requires extensive knowledge as well as time and effort.

g) ISO

An ISO process will have to include all the elements of QC discussed here. It will be able to specify which elements are used at each stage and the intensity to which they are applied. Implementing an ISO process provides an excellent opportunity to optimize the production process and ensure that all the mechanisms of QC are utilized appropriately so that the end product is produced to a known and declared level of uncertainty.

h) Professional Practice

Professional practice reflects the approaches and methods used by the majority of professionals in a field at the current time. As such, it automatically evolves as the various HOs march forward together in the digital age with ENC production.

i) Inspection

At each stage, inspection will be undertaken to ensure that the data's uncertainty conforms to the Standards that were specified in the Planning phase. If the material collected is a spatial object, the elements listed in Section 6 will have to be inspected against the standards, too. Such inspection will require more actions than did inspection in the analogue age, although some of the actions might be automated. QC scripts can currently check the presence or absence or mandatory objects. With newly-collected data, inspecting items like "lineage or history" will be trivial, since there will be only one stage or cycle to examine, but it is vital that the inspection is carried out meticulously since any blunders that escape capture at this stage will appear as problems later on in the production stream. Other factors, such as positional accuracy, will not necessarily be trivial to determine, and must be handled with care.

The inspection applied near the end of the production stream to a complete chart (file) will be more complicated. It is examining how the spatial objects and their uncertainties have been combined, whether there is any negative interference between them, and whether their combined uncertainty meets that specified for the chart. Presumably one result of this inspection is the assignment of S-57 Zone of Confidence (ZOC) to areas within the chart. This inspection will follow uncertainties through the entire production process, beginning with verifying that the each item had an appropriate confidence region. Surveys used on a chart, for example, have to be of appropriate SP44 Order for the chart's planned use. Inspection would then have to verify that the uncertainty required has in fact been met. Each spatial object would have to be inspected for the elements listed in Section 6, unless an earlier inspection could verify them and somehow the process guarantee that the attributes would not be altered during the production process. After verifying the uncertainty of individual classes of spatial objects, inspection would have to verify that the combination of various types of spatial objects on the chart had not degraded the uncertainty of any other element. The final assignment of a ZOC would be the mechanism to inform the mariner of how the uncertainties had combined in the chart he was using. This is a far more active role than that that final inspection once had.

And if ZOC are assigned at this stage, are they to be inspected by a third party?

8. Conclusions and Recommendations

Conclusions

1. In the digital age HOs now need more QC, not less. There is much more information to verify.

2. Once certain attributes of a spatial object have been checked, they should never need to be checked again.

3. That the staff who perform the QC elements, particularly the inspection stages, will have to receive continual and appropriate upgrading of their knowledge and skills.

4. A mechanism for determining the uncertainty of the complete chart needs to be developed.

Recommendations

1. Traditionally, HOs have used approximately similar approaches to QC. This was sound professional practice and helped ensure the safety of the mariner. With the recent rapid transitions, this unity of approach has been weakened to some extent. It is recommended that HOs work together quickly and purposefully to resolve any differences and return to a more unified approach to QC.

2. At present, some HOs plan to estimate uncertainty for each sounding, others to do so for areas, or groups of soundings. This question of to which level uncertainty is determined may also have different answers for other elements that make up a navigation chart. It is recommended that HOs seek a common level of aggregation of uncertainty.

3. That the concept of ZOC be revisited, and consensus sought and implemented on all ENCs.

4. That national standards be re-written to incorporate the implications of new international standards like S-57.

5. That any ISO certification process must include the determination of uncertainty at each stage and of the final product.

The days of using computers and digital data the old way, as if they were simply the same as the previous stuff are over. The real digital era is beginning.

As organizations grapple with the need for a set of clearly defined standards for ENC production. QC workers grapple with how to apply these standards to our ever more complex and changing products.

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