Quality Control in Geophysics

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Abstract

When someone is given an answer to a problem, they almost always want to know, how well is that answer known? Quality control is the process that defines how well the solution is known for a problem. It is preferably given quantitatively, but with real world constraints, that may be only partly possible. The quality control process begins with the definition of the problem to be solved. It then assesses impact on quality from all steps along the way to the solution, and it includes a description of the criteria for a successful solution. These steps include selecting the appropriate tools and procedures to acquire data, determine and describe constraints, document procedures, process data, model data, interpret results, and present the results to the people with the problem, along with an assessment of how well the problem was solved. Quality control includes a variety of subprocesses along the overall path to solution. Some of these include analyses of data measurement error, noise, interference, processing biases, model assumptions, interpreter prejudices, and much more. These require development of procedures and methods to test data, determine errors, recognize and identify sources of noise and interferences, check for and resolve inconsistencies between datasets, test processing, and so forth. Quality control also includes consequences of constraints such as site access limitations, risk, hazards and safety requirements, conflicts and compromises, available resources (including people, equipment, and funding), and other issues (regulatory, litigation, proprietary, security, liability, insurance, training, licenses, customs, etc.). Quality control becomes most important for problems where the answer may be a negative – as in proving the absence of something like a void. Quality control can help answer questions like what is the biggest void that might be there that couldn't be detected by the process performed? These types of questions are often important in hazard and risk analysis, for example in advance of mining. Quality control goes beyond any single discipline, but is discussed here only in the context of geophysics.

Introduction

Answering the question, "How well do you know that?" is often more difficult than the question "How do you know that?" A description of what was done can often answer how do you know, but answering how well requires much more consideration, usually in advance of anything else. Quality control is the process that defines how well the solution is known for a problem, and the process for answering the how well question.

The largest errors in geophysics come from inadequate knowledge of the position and orientation of the measurement sensor. However, the biggest problems in geophysics come from human error: forgetting to charge a battery, incorrect cable assembly, omitting to note the sensor orientation, falling asleep, typing in a wrong number, erasing a file, and so forth. People make mistakes. Equipment fails. Accidents happen. Lightning strikes. A good geophysical field program makes allowances for these events and plans contingencies. This is the beginning of the development of a quality control (QC) program, which with quality assessment (QA) creates a quality assurance program (Taylor, 1985). Quality assessment monitors the quality control processes to make sure they are working, and quality assurance ensures the two produce a verifiable result.

Problem Definition

However, it all really begins with a proper recognition and statement of the problem to be solved. Many people don't really know what their problem is. As an example, I was once asked for help finding a water table. In an area drilled full of monitoring wells, I couldn't believe they didn't know the water table location. After some discussion, it turned out the water table fluctuated, and they needed to know what controlled the level of the water table. That answer turned out to be the seasonal recharge into the subsurface topography of a buried paleochannel in bedrock. The latter is a very different problem than the one originally posed. I've also had people ask about one problem, and during the course of investigation to solve it, uncovered an entirely different and unknown problem, resulting in evolution of the investigation with time. An example is a railroad asking to map ballast thickness and water content, during which it was discovered that the weight of passing trains was causing clay under the ballast to extrude (in the pattern of the ties), eventually resulting in derailment. Another example is mapping highway concrete thickness and discovering abandoned shafts and tunnels from old mining activities. A further example is mapping bedrock topography and soil thickness for foundation engineering and discovering a cache of unknown buried steel drums (with potentially hazardous waste).

Solution Selection

Once the problem is defined, then an appropriate tool (or tools) and procedure(s) must be selected to solve the problem. In geophysics, this involves finding answers to questions like: What are the material contrasts? What is the target size and depth of investigation? What are the required spatial resolutions and accuracy? Is the geometry favorable? If any answer to these questions is unknown, some preliminary tests may be needed to obtain answers. If geometry from the surface is unfavorable, then an alternate geometry such as between boreholes needs to be explored. This latter was the case in the Korean tunnel detection program because surface techniques could not penetrate to the required depth with the requisite resolution, but they could when the methods were put at depth in boreholes.

Once the tools are selected, then the survey parameters and procedures need to be determined: what equipment, frequency, gain, sensor spacing, and so forth?. These have to reside within the boundaries of site logistics, timing, available resources (people, equipment, and funding), hazards, risk and safety, regulatory, training, escorts, insurance, liability, litigation, proprietary, security, notices, permissions, licenses, customs, and other constraints. Survey location geometry needs to be addressed: how will the sensor orientation and location be determined and recorded? What sources of noise and interference need to be considered? What are the contingencies for people getting sick, equipment failure, bad weather, damage in shipping, and so forth.

For most geophysical methods, there are now well developed QA/QC procedures and documentation. A few examples are: APEGGA (2002) for geophysical data in general, ASTM (1999a, b), Olhoeft and Smith (2000) and Tronicke et al. (2000) for ground penetrating radar in specific applications, Badachhape, (2001, 2002) and Widmaier et al. (2002) for seismic, Billings and Richards (2001) for aeromagnetics, Knudsen and Olesen (1998) and Grandjean (1998) for gravity, Teillet et al. (1997) for remote sensing, Theys (1991) for wireline logging, and more. There are also QA/QC procedures that are not method specific but built around particular problem applications, such as environmental site characterization and monitoring (Shampine, 1999; Fuller, 1999; Gillespie et al., 2001; Hernandez et al., 2002; Parsons and Frost, 2002), resource exploration (Vallee, 1999), unexploded ordnance mapping (USACE, 2000), and others (Granato et al., 1998; Han, 1999; Jones, 1999).

Verification and Calibration

Included in the procedures are methods to calibrate and verify instruments are operating correctly, and to test the consistency of the entire system and process. For example, in hole to hole radar tomography, a measurement with the tools at the top of the holes in air (with the known velocity of light in air) should produce a distance between the holes consistent with the position surveying of the hole locations by GPS or laser total station. If they don't agree, something is wrong and must be corrected. In using hole-to-hole radar for tunnel detection, 12 consistency tests are performed before tomographic processing and modeling of the data (Olhoeft, 1988, 1993). If the tests are not passed and the data are processed anyway into tomographic sections, misleading artifacts will appear in the processed results. Another common example consistency test is the use of crossline ties. Often geophysical data are acquired in a grid along east and west or arbitrary x and y orthogonal lines. Where the lines cross, the data at (x,y) along x should equal the data acquired at (x,y) along y (allowing for sensor orientation and out-of-plane effects, Olhoeft, 1994).

Error Analysis

Each independent measurement also should be accompanied by an error analysis, giving the bounds within which the true value lies. The USGS nonlinear complex resistivity system (Olhoeft, 1979, 1985) gives a value and a standard deviation for each measurement, along with signal-to-noise and other parameters useful to determine the quality of measurement. Errors should be computed through a derivative error analysis from the measured quantity through to the final output (such as measured voltage and current with geometry into the material property of resistivity).

Data Processing

Most data require processing. The processing may be to correct for an artifact in data acquisition, an instrument problem, noise or interference, or to enhance some feature in the data (Olhoeft, 2000). What data acquisition condition descriptions and parameter field notes and calibrations or operational verifications will be required for processing? Also, processing can introduce new problems and must be understood. Coherent noise doesn't average out by stacking and may be enhanced by processing. Background removal or other filtering can remove desired horizontal hydrogeological layering as well as undesired artifacts or noise. What does the processing do to the noise as well as the signal? Are there assumptions in the processing that have importance consequences if wrong? The processing of artificial data sets created by modeling is a good way to test processing algorithms.

Modeling

Data may also be modeled --- often to turn a measured parameter into a material physical property spatial distribution, such as apparent resistance and geometry into true resistivity versus depth. Most realistic models still require hours to days of supercomputer time, so assumptions are made to simplify the computation and speed the result. How are the assumptions validated? If the assumption is wrong, what are the consequences? A careful analysis of assumption limitations and consequences is required. If an inverse model is fit to the data, what are the parameter sensitivities and what is the uniqueness of the solution? Computer models must also be validated by tests against physical scale models, known situations, or more exact finite difference time domain or analytical models. Models may also be used to test interpretations and are especially important in testing geometries. Is that reflection underground beneath the measured test line or off to the side and an artifact (Olhoeft, 1994)?

Interpretation

After all this, a human being will interpret and present the results. What are the human biases or prejudices? These may appear not only during interpretation, but earlier in selection of tools, editing, processing and modeling. Was the best and most appropriate tool chosen or simply the most available or most familiar tool? Is the interpreter adequately trained, experienced, and knowledgeable not only about the data, but the data acquisition, processing and modeling that preceded? Are there preconceived notions, not invented here, vested interests, or other pressures (time, money, political) and biases present? Are there multiple solutions that equally well fit the data (ambiguity, uniqueness or equivalence issues)? Are there things that might be masked or hidden because of depth of investigation limitations, resolution issues, noise or interference problems or geometric constraints?

Presentation

When the solution is presented to the problem holder, will the solution make sense? A hydrologist who simply wants water depth in feet does not want to see a geophysical result in two way travel time. The uncertainty and ambiguity should also accompany the solution. An image of data in cross section annotated with station number is much more difficult to use instead of one in map coordinates. Errors in data acquisition, limitations and consequences of processing biases, and so forth should all be discussed. Define what the presented result will look like early in the problem definition process. Make sure the solution matches the problem, and the presentation of the solution is understandable to the people with the problem. In the end, the ultimate quality control is whether or not the solution works for the people with the problem.

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Biography

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