Data Acquisition and Control Automation III
Task Force Report
November 21, 2023

1.0 INTRODUCTION

The Technical Guidance Committee was tasked to review the DACA II document and make any appropriate changes. As a result, the Data Acquisition and Control Automation III (DACA III) Task Force was formed in August 2020, to perform this task. The recommendations in this report are meant to be guidelines for use by test developers/surveillance panels in developing test specifications.

2.0 SCOPE

The DACA III Task Force was charged with specifying minimum performance specifications for Data Acquisition and/or Control systems suitable for use with all targeted testing. These minimum performance requirements shall apply to those parameters that have been defined by the individual test type as being critical. In addition, a means by which TMC engineers can verify compliance of a specific test apparatus will be specified.

3.0 DATA COLLECTION

3.1 Logging Rate:

The maximum period between successive logs of recorded data should be 2 minutes.

During transitions, the minimum required data logging rate is 10% of the allowable transition time, or the steady state logging rate, whichever is fastest.

3.2 System time response:

Refers to the time that a complete data acquisition system takes to log a step change for a given parameter. The complete data acquisition system considers the sensor, any associated wiring leads or piping along with signal conversion, computer processing and any other manipulation of data to the point of logging that would be in place during normal test operation**.**

A system's time response can be determined by measuring the amount of time to reach a certain percentage of an imposed step change. For this document, the value of 63.2 % of the amount of the imposed step change will be used.

For example, for a thermocouple at 25°C ambient temperature being immersed into an ice/water mixture at 0°C, the step change is 25°C. The response time of this measurement system is the time required for the temperature reading to reach 9.2°C:

$$\mathbf{t} = \text{time to (start value - (start value - end value)} \times 0.632)$$

or

$$\mathbf{t} = \text{time to } (25 - (25 - 0) \times 0.632) = \text{time to } 9.2°\text{C}$$

In order to provide an accurate measurement of system time response, a channel may be optionally used to display a triggering switch or signal that indicates when the stimulus was imposed. Response time starts when the stimulus is imposed and ends when the process reaches 63.2% of the final value. In addition, because some system time responses are in the millisecond range, an adequate sampling rate should be used to record values.

Typically, a system that can record and display values at 10 hertz or more frequently is necessary to measure an accurate system time response. Recommended step changes are shown below. If these step change deltas are inadequate, step changes should be at least 100 times the resolution of the measurement system and representative of typical operating conditions when possible. Permanent digital record of the response values and triggering are to be made.

The techniques used to measure response time for typical parameter are as follows:

Parameter	**Step Change**
Temperature	Quickly insert probe at ambient conditions into ice/distilled water mixture to cover the length of the probe. Care must be exercised to ensure that handling of the thermocouple does not change the initial temperature reading, i.e., the temperature plot should be flat prior to inserting into ice bath.
Pressure	Pressurize system to an appropriate value then instantly release pressure. Response time pertains to the response to the release in pressure
Torque	Apply the appropriate load to dynamometer arm. Then remove applied weights quickly from the load cell. Response time will start when the torque signal begins changing.
Speed	Impose a step change to an appropriate r/min at the sensor connection through a frequency generator.
Flow	For flow meters, in general, the system is filled with the appropriate fluid and operated. At the desired time, a shutoff valve is closed and the system response is measured. Other systems will require some other procedure that will have to be determined. Step inputs are typically test area dependent.

Systems are to be designed with components that, when working together, will not exceed the maximum specified system response time.

For each new test type being developed, a particular stand should be designated as the "Golden" stand, i.e. the stand used for test development, from which minimum test requirements will be derived. The maximum allowed response time of each system is derived from a measurement of the system used by the "Golden" stand during the test development.

4.0 STATISTICAL CALCULATIONS

4.1 Quality Index:

The quality of the control of the parameter being measured shall be calculated through the use of the Quality Index (QI):

where U = Upper QI limit
L = Lower QI limit
X_i = Data reading at instance i
N = Number of readings thus far in the tests

$$QI_i = 1 - \frac{1}{n}\sum_{1}^{n}\left(\frac{U + L - 2X_i}{U - L}\right)^2$$

Perfect control of a parameter results in a QI of 1.00. Any deviation from the target lowers the QI. The amount and duration of the deviation affects the final QI for the parameter. How often the QI is updated, and, conversely, how many readings are taken also affect the effectiveness of the QI to capture the quality of the control of the parameter.

For multi-stage tests, the test developer/surveillance panel should determine whether or not a separate QI will be calculated for each stage. If separate Qls are calculated, and a single final QI is desired, the final QI should be an appropriately weighted average of the individual Qls.

The test developer/surveillance panel should determine, for each parameter, whether variations in the signal are random or cyclical. New test development shall include a determination of the cyclic period for each of the parameters of interest to be measured, if applicable. For parameters such as speed, intake vacuum, etc., that have an extremely fast response rate, with a corresponding cyclic period shorter than 2 sec, the minimum required QI sampling period should be determined from data from the Golden stand.

The laboratory systems employed must be able to calculate QI from in-progress test data, either in real time or on command. That is, the QI could be calculated and updated each time a reading is sampled, or the samples logged, and the QI calculated from logged data.

The upper and lower limits for the QI calculations are derived statistically from the operating conditions of the test development "Golden" stand. The limits should be adjusted and set during test development to result in a final QI of approximately .80 to .90 for each parameter on the Golden stand. These limits can be calculated from the operational data. This will result in a uniform criterion for assessing the quality of a test.

If a QI is to be calculated during transitory conditions, then it should be calculated independently from the steady state QI.

For test validity, the QI threshold should be below the QI of the test development Golden stand. This threshold should be determined after sufficient operational data from multiple labs have been generated.

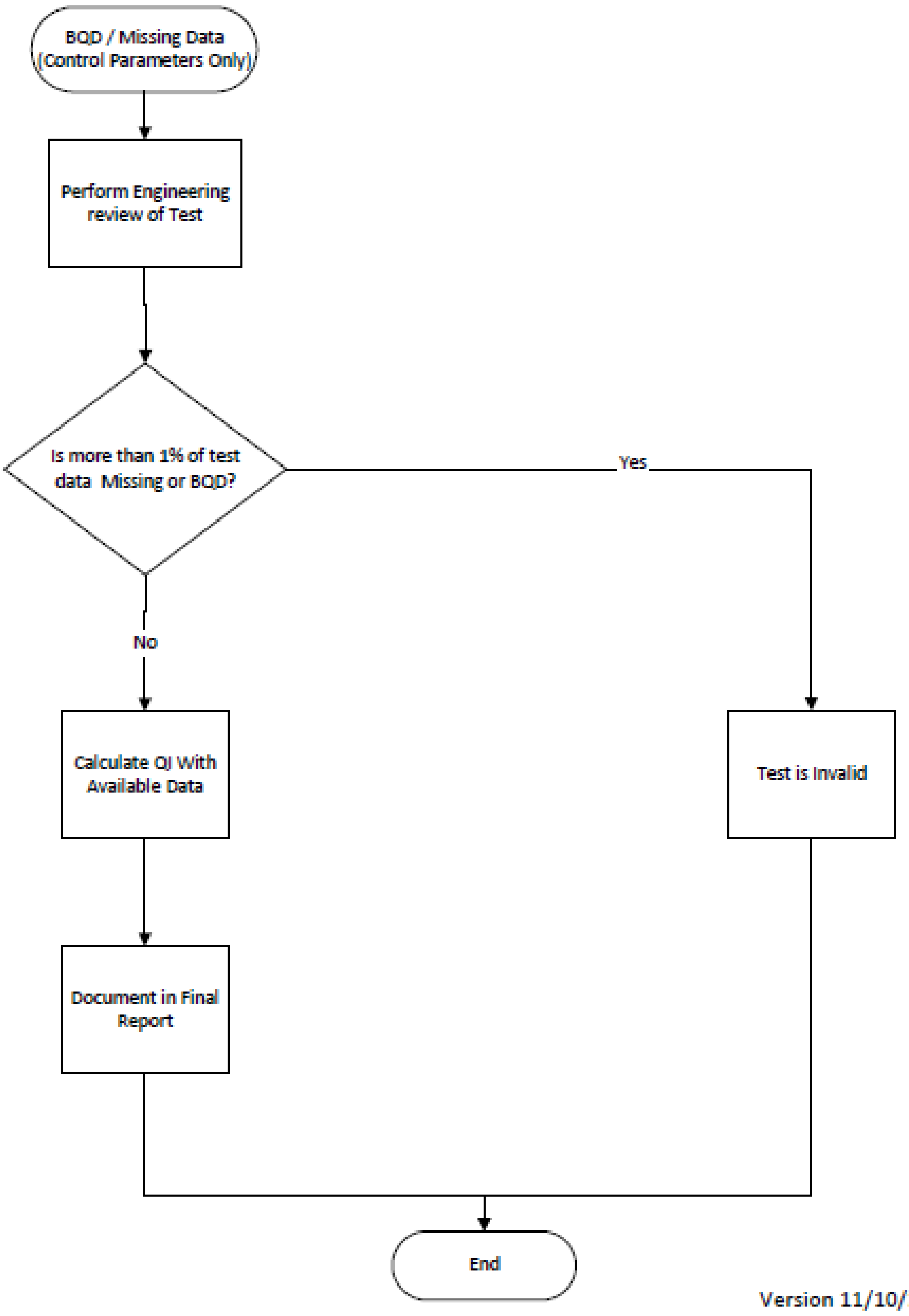
4.2 Bad Quality Data (BQD):

It is possible for the data acquisition system to suffer a temporary malfunction while the control system continues to maintain the proper conditions. These malfunctions may result in missing or erroneous data points (such as 9999 deg C on a temperature). These data points are referred to as Bad Quality Data (BQD). In cases of malfunctions in the test control system, in which the actual test conditions are affected, the deviations must be recorded.

For each occurrence of suspected BQD or missing data, the following flowchart should be used.

In cases where data is labeled as BQD/missing, per the flowchart, the QI is calculated with the available data. If BQD/missing data is greater than 1% of total test data, the test is invalid. In cases where the flowchart does not adequately fit the situation, the final determination of test validity and the disposition of the BQD will depend upon engineering judgment. Any instances of BQD should be explained in the test report comments.

BQD/Missing Data Flow Chart



Version 11/10/2022

5.0 SYSTEM CAPABILITIES

5.1 Accuracy:

The System Accuracy Capabilities Table below is the generic capability of an entire test measurement system based on current conventional cost-effective technology, taking into account reasonable environmental effects.

The inclusion of this table is intended to serve as a guide to the test developers and surveillance panels as to what is commonly possible using current technology and reasonable calibration techniques. It is not intended to be an all-inclusive summary of available technology and specific test types can choose to include tighter or looser specifications, or specify particular instrumentation.

Accuracies are stated for test measurement systems that have been calibrated using due diligence with National Institute of Standards and Technology (NIST) traceable equipment and have been applied using good engineering practices. The recommended method to calculate the system accuracy is the Square Root of the Sum of the Squares of the component accuracy.

Current Measurement System Accuracy Capabilities

Measurement Type	System Type	System Accuracy
Temperature	Thermocouple	0-200° ± 0.50 °C 200-1000° ± 2.00 °C
	RTD	± 0.12 °C
Pressure High (> 6.9 kPa)	Capacitive	± 0.2 % of Full Scale
	Strain	± 0.25 % of Full Scale
Pressure Low (0 - 6.9 kPa)	Capacitive	± 15 Pa
	Strain	± 14 Pa
Flow	Orifice Venturi	0.75% of reading
	Vortex (Liquid) Vortex (Gas)	± 0.75 % of reading ± 3.0 % of Full Scale
	Magnetic	± 1 % of reading
	Coriolis	± 0.25 % of reading
Speed	Frequency	± 1 rpm
Load	Strain Gage	± 0.25% of Full Scale

5.2 Resolution:

Minimum resolution of the acquired data should be at least 4 times the required test measurement system accuracy. Example: Test procedure requires an accuracy of 1.0 N. The minimum resolution is .25 N.

5.3 System Calibration:

The laboratory calibration standards used to calibrate the test measurement system must have an accuracy four times that of the system it is calibrating.

1. The laboratory calibration standards will be traceable to a defined national standard, e.g., National Institute of Standards and Technology (NIST), and be verified at least annually.
2. Test measurement systems shall be calibrated using the laboratory calibration standards mentioned in item 1 above at a frequency as prescribed by the individual test procedures. It is the Task Force's recommendation that all systems be calibrated a minimum of once every six months.
3. Whenever test measurement equipment is changed, the system it is a part of should be calibrated.

5.4 Measurement Uncertainty:

The concept of uncertainty is relatively new in the history of measurement, although error and error analysis have long been a part of the practice of measurement science or metrology. No measurement is exact. When a quantity is measured, the value depends on the measuring system, the measurement procedure, the skill of the operator, the environment, and other effects. Uncertainty of measurement is a parameter associated with the result of a measurement, that quantifies the range of values that could reasonably be attributed to the item being measured.

The “Guide to the Expression of Uncertainty of Measurement” (commonly known as the GUM) is the definitive document on this subject. The GUM has been adopted by all major National Measurement Institutes (NMIs) and by international laboratory accreditation standards such as ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories. Additionally, the American Society of Mechanical Engineers (ASME) has produced a suite of standards addressing various aspects of measurement uncertainty.

When comparing system uncertainty to system accuracy, the analysis should take into consideration the following standard contributors:

1. Repeatability
2. Resolution
3. Reference measurement standard uncertainty
4. Reference measurement standard stability
5. Environmental factors

The five items listed above are the common sources of error that are included in an accuracy assessment and the minimal uncertainty assessment. When considering expanded uncertainty there are many additional sources of error that are included in the assessment as identified in the GUM document. The level of detail needed to describe the process is beyond the scope of the DACA III document. The intent of identifying uncertainty assessment in DACA III is to advise the reader that this methodology is becoming the industry accepted method of measurement uncertainty assessment.

It is the responsibility of the respective surveillance panels to dictate any specific requirements relative to measurement uncertainty. In many cases there can be more or less stringent requirements for a specific test parameter based on the knowledge the surveillance panel has on the potential impact that a specific parameter has on the test results.

6.0 BACKUP DATA:

It is recommended each lab employ sufficient safeguards and redundancy to assure adequate test data logging in the event of electronic systems failure. Examples are redundant data storage, manual logging, screen dump, etc.

Suitable backups should be employed by the labs to use as supporting evidence. The maximum logging interval for these backups should be 1 hour. Missing data should not be more than 1% of the test length.

7.0 DEFINITIONS

7.1 Precision: The degree of mutual agreement between individual measurements from the process.
7.2 Order: The number of energy storage devices in the system. (Most process systems can be reduced to first order, i.e., one dominant energy storage device.)
7.3 Filter: A means of attenuating signals in a given frequency range. They can be mechanical (volume tank, spring, mass) and/or electrical, which can be analog (capacitance, inductance) and/or digital (mathematical formulas). Typically, a low-pass filter attenuates the unwanted high frequency noise. Some signal filtration is necessary in order to assure sampled readings are not compromised due to noise. However, excessive filtration will mask irregularities in the process being measured and can result in an artificially high QI.
7.4 Time Constant (t): A value which represents a measure of the time response of a system. For a first order system responding to a step change in input, it is the time required for the output to reach 63.2% of its final value.

7.5 Cutoff Frequency (f_c): The frequency point that divides the frequencies that pass through the system almost unattenuated and the frequencies that pass through the system but are greatly attenuated. For a first Order system, this value is calculated as follows:

$$f_c = \frac{1}{2\pi\tau}$$

where t is the time constant
7.6 QI Sampling Rate: The rate at which data is acquired for use in the calculation of the QI.
7.7 Sample Frequency (f_s): The frequency at which a value is obtained for processing. This is normally considered for computer data acquisition, but is also true of a manual reading, i.e. once per hour.
7.8 Decibel (dB): A unit for measuring the ratio of the magnitude of two quantities (normally output voltage to input voltage). Calculated as follows:

$$dB = 20 * \log\left(\frac{Output}{Input}\right)$$

7.9 Input Frequency (f_{in}): The frequency of the input signal. This is most certainly changing and includes real but unwanted noise. (Normally the noise is a higher frequency than the frequency of the expected signal.)
7.10 Accuracy: The degree of agreement of an individual measurement with an accepted reference level.
7.11 Data Point: The value of a parameter after appropriate digital/analog filtering with due consideration for the time response of the system.
7.12 Resolution: The smallest increment of an individual measurement that a test measurement system is capable of making.

APPENDIX A
TMC Verification of System Filter Characteristics
INTRODUCTION

Engine Sequence testing laboratories may utilize statistical measures to indicate how tightly critical parameters are controlled. These measures can be affected by the amount of filtering associated with the acquisition of the data. In order to be able to make meaningful comparisons of data between different laboratories, testing procedures should be developed that require use of equivalent electrical and mechanical filtering. Data can be accurately compared and used in statistical calculations only when processed using equivalent filtering strategies that do not overly filter the data signals. The implementation of the testing procedure requires a method by which each lab can be tested to ensure minimum specifications are met. This document suggests verification procedures that could be used.

FILTERS

There are two types of filters to consider when measuring the performance of data acquisition and control systems: mechanical and electrical. Since both mechanical and electrical storage (or filtering) systems can exist in a control loop, the entire end-to-end signal path should be tested to determine a "system" time response.

VERIFICATION PROCESS

Each lab is responsible for meeting or exceeding (i.e., faster response) the procedural system response times for feedback control loops and any other selected parameters. The test developer will utilize a filtering strategy based on the minimum smoothing needed to provide a useable signal. Each lab will submit the known type of electrical and mechanical storage devices along with their loop response times. System response times longer than the maximum allowable response time will not be permitted. The TMC may visit test sites to verify stated filtering techniques and response times. This verification process is as follows:

1) Loop Response Time

Each system will be tested as outlined in the DACA III Report for various parameter types. The loop response time test will capture the system response from sensor to logged value. The response time measurement is based on a time response to 63.2% of final value.

a. Compare response time of test system to response time in procedure on a loop-by-loop basis.

During TMC lab visits engineers may note sensor information (manufacturer, model number, principal employed for measurement, thermocouple type (J, K, E) or RTD, grounded or ungrounded. Also, make note of unusual wiring, piping layout and the use of snubbers, condensate traps or electrical capacitance caps in control panels.

For the purpose of aiding in TMC verification of a laboratory's filtering of input signals to their acquisition system, the step change method will be used. The TMC will use this information to verify that the system response meets the specifications in the test procedure.