

**APPLICATION OF STATISTICAL PROCESS CONTROL AND
PROCESS CAPABILITY ANALYSIS PROCEDURES IN ORBITER PROCESSING ACTIVITIES AT
THE KENNEDY SPACE CENTER**

Robert R. Safford, Ph.D.
Andrew E. Jackson
William W. Swart, Ph.D.

University of Central Florida
Department of Industrial Engineering and Management Systems
P.O. Box 25000
Orlando, Florida 32816

Timothy S. Barth
NASA Kennedy Space Center
Operations Analysis Office
TP-OAO
Kennedy Space Center, Florida 32899

Abstract

Successful ground processing at the Kennedy Space Center (KSC) requires that flight hardware and ground support equipment conform to specifications at tens of thousands of checkpoints. Knowledge of conformance is an essential requirement for launch. That knowledge of conformance at every requisite point does not, however, enable identification of past problems with equipment, or potential problem areas. This paper describes how the introduction of Statistical Process Control and Process Capability Analysis identification procedures into existing shuttle processing procedures can enable identification of potential problem areas and candidates for improvements to increase processing performance measures. Results of a case study describing application of the analysis procedures to Thermal Protection System processing are used to illustrate the benefits of the approaches described in the paper.

Introduction

In his keynote address, at the 1992 S.O.A.R. Conference, Mr. Geoff Giffin, Deputy Director, Operations Thrust NASA/OAST stated: "We live in an era of flat or shrinking budgets. The days of constant growth in NASA and defense budgets appears to be behind us. If we want to do new things, we must reduce the costs of doing existing things - that means operations." In the context of this paper, the term "quality" refers to the areas of productivity and efficiency

as well as the more traditional areas of safety and reliability. KSC shuttle operations has established an industrial engineering function in the Operations Analysis Office to facilitate the systematic institution of shuttle processing operation quality improvements as a way of reducing the costs of processing operations. Research personnel from the Department of Industrial Engineering and Management Systems at the University of Central Florida participate in project activities conducted through the Operations Analysis Office.

Shuttle Processing Operations: Process Performance Measure Data

Conformance to specification (being within acceptable tolerance limits) is essential to Space Shuttle processing. However, to the individual needing to identify processes for improvement or desiring to quantify the potential for improvement in a process, knowledge of the fact that specifications were conformed to and requirements were met, is not sufficient information. The statistical process control procedures necessary for continuous improvement of processes require that actual variables data values of Process Performance Measures (PPMs) be available for analysis. Space Shuttle ground processing at Kennedy Space Center (KSC) involves the execution of thousands of written work instructions. In addition to "buying off" steps in the work instructions after they are properly completed, "variable" data elements are frequently collected during the execution of the work step. Examples of variable data elements are:

- Torque readings
- Leak rates form mass spectrometer probe operations
- Ambient temperature readings
- Results of visual inspection for damage and debris
- Calibration numbers and due dates for tools and ground support equipment (GSE)

The variable data elements are currently recorded when engineers and technicians fill in blanks in the paper work instructions. The variables data is mainly used for real-time control of work steps (to ensure functional conformance to specifications). However, the only way to retrieve past variables data is through a labor-intensive paper or microfilm search of the completed work instructions.

Ready availability of these PPM variables data values would enable relatively easy determination of:

- Control charts for delineation of common and special causes
- Process capability analysis

- Continuous process performance monitoring procedures
- Other useful statistical process control tools

Variables data consist of measurement values, usually defined on a continuum (e.g. length, time, pressure, pull weight, etc.). Variables data complement attribute data which classify the output of a process as conforming or non-conforming to requirements. Variables data combined with the information that defines requirements for performance enables the determination of process capability and the qualification of processes for use in operations targeting high levels of quality performance.

As organizations grow in their awareness to improve processes (and, thus, reduce cost and raise productivity), increased usage of attribute data to control and stabilize factors affecting end product quality is required. As relatively high levels of quality and accompanying low levels of non-conformance or defective product is realized, continued process improvement demands variables data. This is particularly true in "low volume" operations desiring to certify processes for high levels of quality (e.g. satisfaction of criteria for flight requiring one in a million or less probability of non-conformance.)

Statistical Process Control and Capability Analysis

Total Quality Management (TQM)/Continuous Improvement Process (CIP) is based on statistical process control (SPC). SPC is the foundation for measurement based process improvement activity. An important aspect of SPC used for process improvement is capability analysis.

Process "capability" is a measure of the natural behavior of a process after the process has been stabilized by the removal of all special or assignable causes. Special or assignable causes affect the process performance measures but are not considered to be causes that

are part of the process. A process must be stabilized and have an established process capability before process improvement can be measured.

Process capability analyses associated with process performance measures described by variables data express the process capability in terms of the probability distributions of the statistics characterizing the PPMs.

In the absence of specification limits for a process performance measure, the process capability is expressed in terms of the "spread" of probability distributions of the PPM around its center. The width of the interval encompassing plus or minus three standard deviations around the mean of the distribution is usually chosen as an expression of the process capability. When specification limits for the Process Performance Measures are given a process capability index based on the ratio of the spread of the distribution to the width of the interval defined by the specification limits.

Capability index values can be related to probabilities that measures will exceed specification limits as indicated in Table I below.

Capability Index	Probability that Measure will <i>Exceed</i> Specification Limit
.5	.0668
1.0	.0013
1.5	1.515×10^{-5}
2.0	1×10^{-9}

Table I - Capability Index

Thermal Protection System Analysis

A structured analysis was conducted of Thermal Protection System (TPS) processing activities at the Kennedy Space Center to identify candidates for processing improvement and to evaluate statistical tools in the operational environment supporting Space Shuttle process-

ing. As part of this activity, the primary customers of any methods improvement activities were considered to be the technicians who were performing the work on the floor of the Orbiter Processing Facilities (OPFs). As such, they were queried about the processing activities which could benefit most from a detailed analysis. A survey was distributed to the TPS Engineering Team, the TPS Quality Team and the TPS Technicians responsible for maintenance of the flight critical Thermal Protection System on the Orbiters. These surveys were collected and analyzed to identify potential sources of methods improvements. Attention was then focused on the top 20 candidates for improvement. A procedure was identified which cuts across several of the top ranked processes. This procedure was a temperature measurement task to compare the OPF ambient temperature with the Orbiter Vehicle substrate temperature in an attempt to identify conditions which would increase the probability of moisture formation at the vehicle substrate surface. The temperature/dew point differential criteria used was an ambient temperature reading three degrees (or more) higher than the substrate temperature. Conditions outside this tolerance would favor moisture formation under certain humidity conditions, thus preventing proper bonding of the TPS components. Discussions with several technicians and engineers indicated the temperature measurement process was unnecessary in the controlled conditions of the OPFs and should be eliminated. The major issue was the requirement to perform a Process 217 (P-217) Temperature/Dew point stabilization procedure for any out-of-tolerance conditions identified by the temperature measurements. P-217 is a time consuming and complex procedure to stabilize the temperature of the substrate prior to bonding TPS components. Therefore, it is well suited to an analytical review, based on the capability analysis procedure cited herein. Although P-217 is seldom called out in the OPF as a result of an out-of-tolerance temperature condition, the requirement to continuously check for the temperature differential consumes significant manpower resources and creates unnecessary expenses centered

Orbiter Vehicle	Flow	Capability	# of σ
OV 104	11	1.12	3.36
OV 104	10	1.11	3.33
OV 105	2	1.11	3.33
OV 104	8	.69	2.07
OV 102	11	1.67	5.01
OV 105	1	1.03	3.09
OV 103	8	1.48	4.44
OV 102	8	1.19	3.57
OV 104	6	1.07	3.21

Table II - Capability Analysis Summary Matrix

around training, re-training, as well as the purchase, calibration and maintenance of the temperature measurement pyrometers.

An Application of Capability Analysis

As part of this research activity, a capability analysis of the Environmental Control Systems for all three OPFs was performed. This analysis was conducted to insure the OPFs could be consistently maintained at the proper atmospheric conditions to insure proper bonding criteria for TPS components. A procedure is now in place which requires the measurement of ambient OPF temperatures and the orbiter substrate temperatures to minimize the possibility of moisture formation on the substrate surface of the Orbiter which could adversely affect proper TPS bonding criteria. The capability analysis was done in support of an analysis to validate the need to perform this temperature measurement procedure in the controlled environment of the OPFs. Over 119 temperature measurements were analyzed based on a random selection process covering all four Orbiter Vehicles, all three OPF bays and all four seasonal conditions in Central Florida. The results of the capability analysis, computed for each set of sample data are shown in Table II above. This analysis quantifies the capability of the OPF Environmental Control System to provide the necessary stabilized temperature conditions which would preclude P-217 from being called out. Numbers support the contention of the TPS technicians and engineers that the temperature measurement is not required. Formal review procedures are

being initiated to consider deletion of the temperature measurement requirement.

A capability value of 1.0 indicates a 3 sigma (3σ) or $\cong 99.8\%$ probability that temperatures will be within specified limits. It should also be noted that the variability inherent in the temperature readings for ambient and substrate temperatures *includes* variability for the temperature itself (the variable of interest), the equipment tolerances, and the measurement processes. The measurement process includes variability due to operator techniques,

