

**1996 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM
JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA**

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STATISTICAL PROCESS CONTROL FOR KSC PROCESSING

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Contract Number NASA-NGT10-52605

August 9, 1996

ABSTRACT

The 1996 Summer Faculty Fellowship Program at Kennedy Space Center (KSC) served as the basis for the research effort into Statistical Process Control for KSC Processing. The effort entailed several tasks and goals. The first was to develop a customized Statistical Process Control (SPC) course to be taught to the Safety and Mission Assurance Trends Analysis group. The actual teaching of this course took place over several weeks. In addition, an Internet version of the same course complete with animation and video excerpts from the course when it was taught at KSC was developed. The Application of SPC to Shuttle Processing took up the rest of the summer research project. This effort entailed the evaluation of SPC use at KSC, both present and potential, due to the change in roles for NASA and the Single Flight Operations Contract (SFOC). Individual consulting on SPC use was accomplished as well as evaluation of SPC software for KSC use in the future. A final accomplishment of orientation of the author to NASA changes, terminology, data format, and new NSA task definitions will allow future consultation when the needs arise.

STATISTICAL PROCESS CONTROL FOR KSC PROCESSING

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1. INTRODUCTION

The use of Statistical Process Control (SPC) at Kennedy Space Center (KSC) was the focus of this research effort for the Summer of 1996. The research effort is broken down into several tasks that were accomplished over the course of the summer. Those tasks were:

- Development of a customized KSC Statistical Process Control course to be taught to Safety and Mission Assurance Trend Analysis Group and any others interested
- Teaching the developed SPC course
- Developing an Internet version of the SPC course for the benefit of Safety and Mission Assurance (S&MA) management
- The evaluation of the application of SPC to Shuttle processing both present and future
- Evaluation of SPC software for use by S&MA personnel
- Establish a working relationship with the people involved with Shuttle processing analysis, the terminology and procedures involved in Shuttle processing, and become familiar with the type of data gathered in the course of Shuttle processing in order to be able to act as consultant to the analysis effort in the future

NASA has been required, due to budget considerations, to change its role in Shuttle Operations. From an historic partnership and combined effort with contractors in the pursuit of space flight, now NASA is faced with assuming a caretaker or managerial "hands off" role for the future of the Shuttle program. This is a significant cultural change requiring the need to utilize all of the techniques from industry available to increase efficiencies, reduce rework, gain control and identify causes for excessive costs, reduction in inspections and surveillance routines, reductions in manpower, and reduce the throughput time necessary for each cycle of the orbiters from blastoff to blastoff. Statistical Process Control is a significant tool to assist in the success of NASA's new managerial role because it can assist in determining the reasons for process variation leading to decreased costs.

In order to use SPC within the KSC environment, pertinent personnel need training in the proper use of the technique. The training must extend from the top down, meaning upper management must be knowledgeable in SPC techniques as well as the analyst working with the data. Training has been and will be accomplished in two ways: first, a customized SPC course was developed and taught to the analysts who will be performing the majority of the analyses; and second, an Internet version of the same course will be finished soon for the use of anyone, especially top management, who desires or is required to utilize SPC techniques. The web-based course is full of animation, video from the course when it was taught at KSC, interactive tools for statistical calculation, and the charts, search capabilities, and "Frequently Asked Questions" (FAQ) needed to make the product useful at any time.

The need to assess current use of SPC techniques as to appropriateness, correctness, completeness, and existence where needed was foremost in the task of application of SPC to Shuttle processing. Then came the consultation with various individuals as to the approach recommended to gain control of the various processes. The three approaches to SPC analysis discussed, in order of recommended application, are metrics (descriptive statistics), attribute charting technique for nonconformance data, and variable charting techniques for measurement data. This effort, in particular, is an on-going one covering, perhaps, the next three to five years. Management at the highest levels within NASA must understand what to expect in order to get processes under statistical control as well as understand what decisions to make and when to make them based on the SPC techniques.

SPC software for KSC use was evaluated. The SAS Institute's JMP statistical software package was in residence and deemed to be the most powerful and speedy even though explanations were scant.

2. Statistical Process Control Course Development, Teaching, and Internet Version

SPC can be a very easy to use technique and a very difficult one as well. There is a definite sequence that is recommended to be followed when implementing SPC into any situation, especially one in which the knowledge level of SPC is relatively low or there are misconceptions. Unfortunately, these conditions exist virtually everywhere and certainly existed at NASA at the beginning of the Summer of 1996.

Because of this need to know the proper sequence in which to implement SPC, and the possible difficulty that some have with understanding of the statistical theory involved with SPC, a course customized to KSC was developed this summer. The course was entitled "Quality Control NASA Style", and it was designed for six sessions of two hours each for a total of 12 hours. The last session was to be a computer lab class where SPC software could be demonstrated and practiced upon.

The SPC course was divided into six days of PowerPoint presentations covering the following topics:

I. Day One

- A. Concepts of Quality - Definitions of Quality
- B. Inspection versus Prevention
- C. Quality by Design
- D. Accuracy and Precision
- E. History of Quality Control
- F. Seven Basic Tools
- G. Statistical Inference
- H. Probability
- I. Descriptive Statistics
- J. Constructing a Frequency Distribution

II. Day Two

- A. Advanced Statistics and Probability
- B. Measures of Central Tendency
- C. Measures of Dispersion
- D. Definitions of Probability
- E. Permutations
- F. Combinations
- G. Important Discrete Distributions

III. Day Three

- A. Important Continuous Distributions
- B. The Central Limit Theorem
- C. Statistical Process Control
- D. SPC is an Attitude
- E. Variation
- F. Control Chart Basics
- G. Kinds of Control Charts
- H. Operating Characteristic Curves
- I. Implementing SPC
- J. Traditional Applications of SPC
- K. Non-Traditional Applications of SPC

- L. Control Charts for Attributes
- M. Kinds of Attribute Charts
- N. Construction of a p Chart
- O. p Chart Interpretation

IV. Day Four

- A. Control Charts for Variables
- B. Construction of a Variables Control Chart
- C. Interpret Variables Control Chart

V. Day Five

- A. Basic Questions on Variable Charts
- B. Process In Control
- C. Process Out of Control
- D. Process Capability
- E. Calculate Capability Index
- F. Interpretation of Capability Index
- G. Other SPC Techniques
- H. Other Control Charts
- I. Reliability
- J. Reliability Measurement
- K. Types of Failure
- L. Historic Bathtub Curve
- M. Cost of Reliability
- N. Taguchi Loss Function

VI. Day Six - Computer Lab Instruction on SPC Software

The course was presented to personnel twice per week for three weeks from the Safety and Mission Assurance Directorate and specifically the Safety group, Trend Analysis group, some summer interns, and members of the I-NET multimedia group who would be working on the Internet version of the course.

The Internet version of the course is entitled "Introduction to Statistical Process Control". The opening page of the Internet course is depicted in Figure 1. The course, at the time of this final research report, is approximately 75% complete and should be ready to go by September 1, 1996. The NASA internal Internet address is <http://kosh/spc/>. The Internet version contains

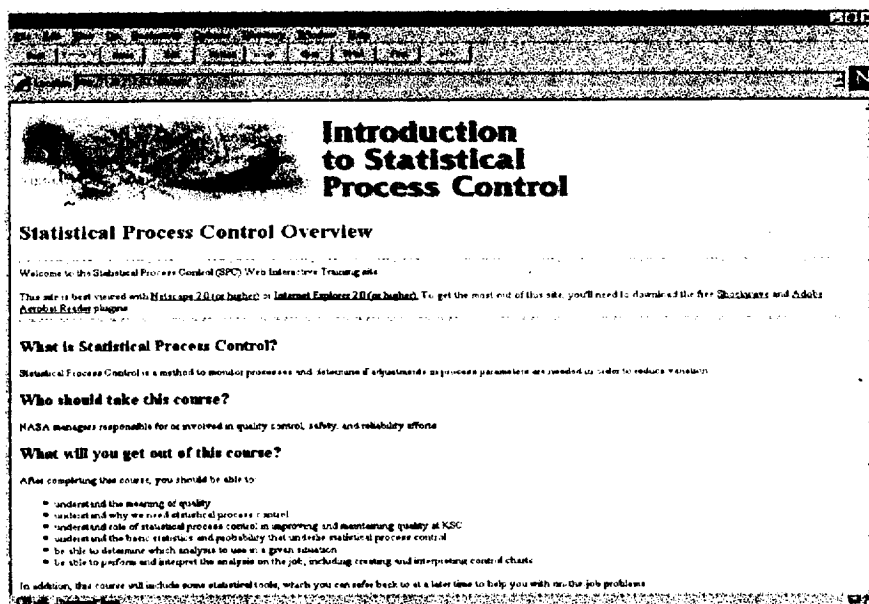


Figure 1. Sample SPC Course Web Page

essentially everything that the original course contained with the addition of animated graphics, interactive statistical calculation tools, exercises that need to be completed before progression into the course, a search engine fully referenced to the entire course, "Frequently Asked Questions" (FAQ) section, and links to the original PowerPoint presentations. If utilized by management, this on-line course will make the successful difference for SPC as a cost reduction too at NASA KSC.

3. Application of SPC to Shuttle Processing

NASA in Transition

There is a cultural change and a transitional process currently underway at NASA KSC. The best manner in which to describe what is going on is to examine a time line. There was the way NASA conducted Shuttle Operations in the past, there is the transition or how things are happening at the present time, and what will be when the transition is over and NASA's role has changed.

Was

The cultural change now underway relates back to the way things used to be done at KSC. Ever since the beginnings of NASA itself and manned space flight in the late 1950's and early 1960's, NASA has worked alongside contractors who provided the hardware for the missions. NASA did "hands on" work on a day-to-day basis, was involved in the on-site inspection and testing of the components, and had a partner relationship with the contractors over the years. This compatible relationship was successful in a mission sense. Goals like putting man into space, orbiting the earth, going to the moon, putting a man on the moon, the Space Shuttle program, etc., were all accomplished with only a few problems along the way.

The culture that saw this sympathetic and compatible relationship between NASA and its contractors also had few concerns concerning money. The programs were goal oriented, not cost conscious. If something was a problem, they just kept working on it until it was fixed and operational.

Transition

The current situation at NASA KSC can be identified as one in a state of transition. The United States government over the last ten to fifteen years has amassed an enormous national debt for a number of reasons. The annual deficit has continually added to the national debt year after year. Therefore, there is tremendous pressure on the politicians to decrease the annual deficit and thereby not adding to the national debt. Budget cutting of governmental agencies is one manner in which reductions in the U.S. government budget decreases deficit spending. NASA's budget has fallen victim to these budget cuts necessitating the need for NASA to change its role in the manner in which it conducts Shuttle Operations.

NASA is changing into a caretaker or oversight role from the contractor/partner relationship it enjoyed for so many years and over so many programs. There is a transition period when NASA must first realize that there is a change needed due to the different budgetary constraints, and secondarily figure out just how that change effects daily operations as well as the realization that the contractors will be doing all of the "hands on" work while NASA only verifies the results.

During the current transition period, which will probably last only a short time, the NASA efforts should be concentrated in the collection of pertinent data to be analyzed as comparisons to "before the transition" and "after the transition". The pertinent data to be collected is one of the decisions to be made. What metric technique for the chosen processes is another decision to be made. It should be pointed out that the recommended sequence for metric choice is simple before complex. Most processes can be evaluated with simple metrics and simple analysis

in order for management decisions to be made and verification of data to be made. It is easier to increase the complexity of analysis from an elementary level than it is to start with complexity and lose credibility.

Another important outcome of the transition period is a defined role for the analysis group after the transition. It is a reality that no one really knows what the post-transition environment will be like. Therefore, the data that is collected and analyzed, by what analytical methods, and how often will define the role of the analysis function to a great degree during the transition period. Goal determination for the analysis function should also be defined during the transition because of the timing of the contracts that take control of Shuttle Operations by contractors. If goals for analysis by NASA are not part of the contracts, it will be very hard to implement analysis after contract award and contract start.

Management is the key to success of any statistical analysis effort. If management either does not understand the statistics involved or how to interpret the results of the analysis in order to improve the conditions of the processes, then, essentially, the analysis effort is wasted. The true payback of the SPC technique actually *begins* with the charting of the process. Management at the highest levels (Center Director, Director, on down) must be able to assess the statistical control status of the selected processes in order to make decisions about reducing variation leading to reduced costs and reduced pressures. The transition period is a prime time for management to become trained (through the web-based course) in SPC and the associated interpretation of the analyses. Continuous improvement is the goal of SPC. Continuous improvement means lower costs. Proper use of SPC means processes under control. Processes under control mean higher quality at reduced costs.

Will Be

The new oversight role that NASA KSC is transitioning into is analogous to management in private industry. Industry management must always seek to produce at higher quality, reduced costs, and faster delivery because of competition. NASA KSC has all three of these components influencing their very survival in the next twenty years unlike what they experienced in prior years. Verification of contractor data now becomes the primary function of Mission Assurance. But just checking for validity in contractor reporting of data is not enough to determine if contractors are performing up to contract expectations. NASA must maintain the ability to perform selective data evaluation from contractor provided data independent of the contractor's reporting. In this way, the contractor can be held accountable for virtually anything that they do and not just on what they report.

A most important point can be made here also. That is that NASA KSC now can benchmark their operation to those of industry. Because of the competition factor, the cost sensitivity factor, and the continuing need for high quality, concepts such as Total Quality Management (TQM), Statistical Process Control (SPC), Just-In-Time (JIT) techniques, ISO 9000 requirements and certification standards, the criteria of the Malcolm Baldrige National Quality Award, and individual benchmarking measures such as wage levels, overhead rates, quality levels, safety performance, maintenance rates, etc., all now apply to Shuttle Operations at NASA KSC. In fact, these concepts and comparisons should contribute greatly to the overall goal of NASA KSC of a successful Shuttle program run efficiently and on budget.

Statistical Process Control

The use of Statistical Process Control is varied, versatile, and structured. Many users assume that the more complexity of the technique, the more help is received. This may be true in some cases. However, more than 75% of all data analysis can be done successfully and completely with just simple metrics such as bar charts, Pareto analysis, flow charts, etc. Why jump into a variable control chart analysis with all of the associated knowledge needed about statistics and how to interpret the chart correctly when Pareto analysis might give the order of the most significant problems to address.

The recommended sequence for the implementation of SPC techniques is: first, metrics; second, attribute control charting; and, third, variable control charting.

Metrics

SPC techniques such as bar charts, Pareto analysis, check sheets, flow charting, cause/effect diagrams, frequency distributions, and scatter diagrams can be classified as easy to learn but very revealing for data analysis. More than 75% of all data analysis can be completely accomplished through the use of these “seven tools”. Therefore, they should always be the starting point of any problem areas in need of analysis. They are easy to use, easy to teach, easy to understand, easy to interpret, easy to implement, and highly effective. Management can make decisions concerning cost reductions, efficiencies, and scheduling of manpower based on them. Risk analysis can be based on them. The use of simple metrics to define problems in processes by simple analysis should always be the first tool pulled from the SPC toolbox.

Statistical Analysis - Attribute Charting

When the data that needs to be analyzed falls under the category of attribute data, or go-no go, conforming/nonconforming, good/bad, etc., and statistical analysis is needed to determine if the data is operating in statistical control or not, then attribute charting is required. The data is target oriented meaning that there should be some chosen desired value for a process target. The data has a

mean, but the mean may or may not be at the desired target. When

the process control limits are calculated, the attribute data target is used to see if the process is even close to the desired value of the target. Therefore, the first management decision may well be to reset the desired target value to the process mean or to find out why the process mean is so far from the target value. An example of NASA KSC lost time cases rate for every 200,000 hours worked is shown in Figure 2.

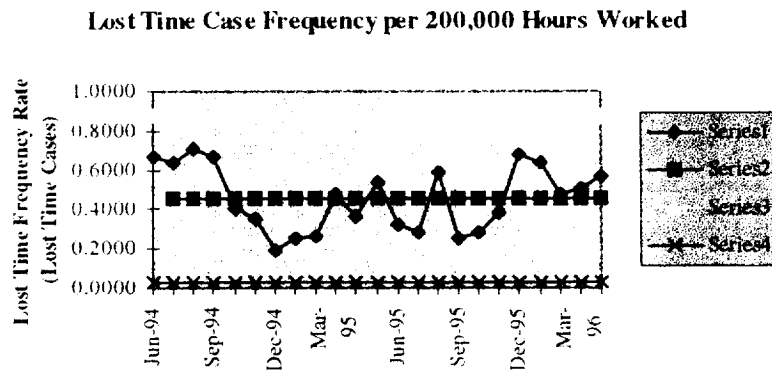


Figure 2. Sample Attribute Chart

When the process mean is used as the target and the control limits are calculated, outliers can be found which are points outside of the control limits. These points warrant investigation as to the reasons for the assignable causes relating to the points out of control. Then limits are recalculated without the outlier data, and the new chart with its recalculated control limits is evaluated again. This is done repeatedly until there are no points out of control. The process is then said to be “in control” which simply means that only random error is causing variation in the process. In this manner, 99.73% of all data should fall within the control limits. If any point falls outside of the limits, then an assignable cause is associated with the occurrence, the cause can be fixed, and management can continue to be confident in the output of the process without adjustment. There are also many other interpretation skills necessary to utilize control charts efficiently. These are discussed in the Internet version of the SPC course.

Statistical Analysis - Variable Charting

Whenever descriptive statistics, metrics, or attribute charting has highlighted an area that is in need of further or a

greater degree of scrutiny, then, perhaps, variable SPC charting is warranted (see Figure 3). The data must be in the form of continuous measurement data unlike attribute data which is, essentially, binary in nature. The difficulty with the understanding of the level of statistics involved with variable charting makes it the last resort which gives the greatest amount of information of all of the SPC techniques. For these reasons, variable charting should be used cautiously and only when necessary. In the author's experience, this technique is the most frequently misused, misapplied, and misinterpreted.

As with attribute charting, variable charting gives the state of control of the process, assesses the variability of the process, and provides management basis for decisions concerning the quality of the processes. The actual manipulation of the data is different from attribute charting. However, the interpretation of the chart is essentially the same. It is very important that the pertinent people involved in the process be the ones to investigate the outliers because of the need to involve everyone in the gaining of control of the process in question. The process drives continuous improvement and continuous improvement is, or should be, the goal of any process.

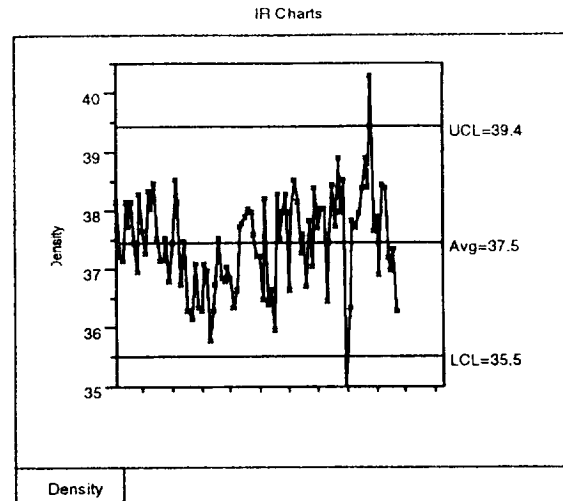


Figure 3. Sample Variable Chart - BTA Material

4. Expertise Shared as Internal Summer Consultation

There were several opportunities to do Statistical Process Control and statistics consulting with the people from RM. Some of the significant ones were:

- Jerrace Mack - RM → Inspection data correlation with structured surveillance data; first time quality data analysis
- Lisa Pantano - Safety → Monthly Mishap Severity Rate chart consultation from p chart to u chart because of Poisson distribution of rates
- Jim Lichtenhal - QE group → candidates for MIP reduction SPC analysis

5. SPC Software Evaluation

If SPC is to be utilized to its maximum efficiency at NASA KSC, software has to be utilized that is capable, accurate, easy to use, and fast. After looking at several packages provided by KSC and one brought by the author, the SAS Institute's JMP Statistical Discovery Software was found to be the most powerful. It also had the advantage of already being on-site and in limited use.

When data analysis is being performed on large data bases, this software almost immediately can formulate data into any number of needed methods of analysis from histograms to Pareto analysis to frequency distributions to control charts of both attribute and variable data. In short, this software is impressive. The only drawback is the lack of explanation for the novice. This again accentuates the worth of the on-line SPC course to provide the tutorials necessary for efficient use of the software.

6. Orientation for Future Consultation

One of the original goals of this summer's activities was to provide the author with sufficient orientation to NASA KSC's terminology, data gathering, organizational structure, and facilities so that an on-going relationship could be maintained for SPC consultation. In the immediate and distant future when questions arise concerning the

statistical analysis of contractor data by NASA, the need for consultation may become necessary. Now that orientation provided by this summer's research fellowship is completed, phone communication, fax communication, etc., can be utilized to provide direct and timely consultation.

7. Conclusions and Recommendations

As a result of the Summer Faculty Fellowship time spent and the analyses done, the following conclusions and recommendations are offered:

- Assess current attribute charts concerning visibility of ± 3 sigma standard deviations from the process mean
- Assess current attribute charts for showing process average as the process target
- Recalculate control limits quarterly to determine if change has occurred - narrowing of limits indicates decreased variation and a tighter degree of control and a widening set of limits indicates increased variation and less control
- List all processes in the VAB, OPFs, launch pads, etc., where attribute data or measured data is collected as candidates for analysis by SPC techniques
- Do SPC analysis using JMP software on all candidate processes for determination of status of statistical control
- Based on SPC analysis, if in control, then basis for continued control is established
- Based on SPC analysis, if out of control, then begin determination of causes for out of control points, elimination of assignable cause data from database, recalculation of control limits, determination of causes of out of control points, etc., until stable in control limits are found
- Management decisions can be made during this process of gaining control and after control is established to accomplish the following:
 - ⇒ optimize the use of resources
 - ⇒ reduce amount of inspections
 - ⇒ eliminate, correct, or reduce inspections (material qualification, test specimen preparation, correlation with weather data, consistent employee procedures, etc.)
 - ⇒ Reduction in manpower requirements
 - ⇒ Risk assessment
 - ⇒ Correlation of charting with Problem Resolution (PR) rates and PR severity data (number of pages per PR)