

Shewhart Charts with Multiple Phases

Robert J. Scharl, LTV Steel Company, Cleveland, Ohio

Abstract

SAS® has an excellent procedure in SAS/QC® to easily construct control charts with a single set of control limits. When a process requires multiple sets of control limits (phases), it requires multiple passes through the data to define all the necessary limits' data sets. When expanded to many process variables, the required SAS® code can very quickly become unmanageable.

This paper will demonstrate the use of macros to generate a control chart having only one (1) phase to many phases (limited only by the readability of the chart). The out of control points are annotated. Recalculation of the limits' data by eliminating points when a specified value above or below the control limit is exceeded. A log of all phase changes is maintained. The starting observation for display can be anywhere in any phase. The 'x' axis can be reformatted to various date formats.

Problem

American business has realized the need for Statistical Process Control (SPC) when the world became a global market. No longer could business give the customer what it thought it wanted. Business had to supply what the customer wanted. The merchandise had to last longer than before and had to have tighter tolerances to compete in this ever expanding world market. To achieve the tighter controls, it became necessary for industry to control their process and products with control charts. The control charting lead to continuous process improvement.

The first line process control remains with the operator producing the product. However, there is also the need to produce massive numbers of control charts from historic data. The charts may span a greater time period than the first line charts. A process or product may exhibit several process shifts that require different control limits.

PROC SHEWHART® in SAS/QC® gives the computer user the ability to produce control charts from historic data. It is fairly easy to produce one chart that has several different phases. But to produce and reproduce hundreds of charts on a routine basis with

many phases will soon become a logistic nightmare to maintain the SAS® code.

It soon became apparent that a 'CORE' program was needed that would be easy to maintain, allow multiple phases, maintain a historic trace of process (product) improvement, produce many chart styles, annotate 'out-of-control' points and exclude points in calculation of the control limits that exceed a set multiple of the standard deviation.

The Solution

SAS® Procs assume that all incoming data set will have all variables completely defined. The basic proc does not allow for the creation of certain key variables to be done 'on the fly'. Within PROC SHEWHART®, the variables 'phase' and 'index' must be defined if a phase chart is to be produced.

The *subgroup-variable* for all control charts is a date, either in a DATE5 or MONYY format. A type of date label is displayed on the charts for the phases.

```
%LET DATASET = MYDATA;  
%LET CHART = "TYPE OF SHEWHART CHART DESIRED";  
%LET VERT = "PROCESS VARIABLE";  
%LET DATE1 = 'FIRST DATE'; **** FORMAT '01JAN94'D;  
%LET DATE2 = 'SECOND DATE'; **** FORMAT '01JAN94'D;  
%LET DATE3 = 'THIRD DATE'; **** FORMAT '01JAN94'D;  
%LET DATE4 = 'FOURTH DATE'; **** FORMAT '01JAN94'D;  
%LET N = 4; **** NUMBER OF PHASES;
```

For execution, certain key variables must be supplied to the program:

1. %LET DATASET defines the master data set where the process variables reside that are to be processed.
2. %LET CHART defines the type of Shewhart that is to be produced.
3. %LET VERT defines the *process* variable that is to be analyzed.
4. %LET DATE n defines the beginning and ending date for the phases.
5. %LET N defines how many phases are to be included on the chart. N will be equal to the last value of n defined by the last %LET DATE n statement. N also defines how many times macro statements will execute.

Program Explanation

%MACRO PHAS sets the macro variable PH&I which acts as a place holder for the passage of the phase definitions created in MACRO PHASE. (See the %GLOBAL statement in MACRO PHASE).

```
%MACRO PHAS;
  %DO I=1 %TO &N;
    PH&I
  %END;
%MEND
```

%MACRO PHASE creates the actual label for the phase and index statements. It is a requirement for the history and limits data sets for creation of the final Shewhart chart. The macro will take the %LET DATE*n* in consecutive groups of two (2) for creation of the phase / index label. The %PHAS in the %GLOBAL statement is required to pass the created macro var.'s &PH&I to subsequent steps.

```
%MACRO PHASE;
%GLOBAL J %PHAS;
DATA _NULL_;
%DO I=1 %TO &N;
  LENGTH CNT $ 1 PH&I $ 11 MDATE $ 5;
  %LET J = %EVAL(&I + 1);
  %IF &I < &N %THEN %DO;
    PH&I = LEFT(TRIM(PUT("&&DATE&I"D,MONYY5.))) ||
    ' ' ||
    LEFT(TRIM(PUT("&&DATE&J"D - 1,MONYY5.)));
    CNT = LEFT(TRIM(&I));
    CALL SYMPUT('PH' || CNT, PH&I);
  %END;
  %IF &I = &N %THEN %DO;
    J = &J;
    MDATE = PUT(TODAY(), MONYY.);
    PH&I = LEFT(TRIM(PUT("&&DATE&I"D,MONYY5.))) || ' ' ||
    MDATE;
    CNT = LEFT(TRIM(&I));
    CALL SYMPUT('PH' || CNT, PH&I);
    RETAIN;
  %END;
%END;
RUN;
%MEND
```

%MACRO LIM will concatenate the individual LIMITS data sets.

```
%MACRO LIM;
  %DO I=1 %TO (&N - 1);
    LIM&I
  %END;
%MEND;
```

%MACRO HIS will concatenate the individual HISTORY data sets.

```
%MACRO HIS;
  %DO I=1 %TO &N;
    HIST&I
  %END;
%MEND;
```

%MACRO SHEW is the real workhorse of the procedure.

```
DATA D; SET &MYDATA;
  **** SUBSET DATA AS REQUIRED ****;
  COMMENT = ???????????;
```

If you desire to annotate your chart with a reason for the out-of-control point, insert the logic calling the variable name **COMMENT**.

```
%DO I=1 %TO &N;
  %IF &I < &N %THEN %DO;
    %LET M = %EVAL(&I+1);
```

Establish the process sequence for the combinations for the date sequences.

```
PROC SHEWHART DATA=D;
  WHERE ("&&DATE&I"D <= DATE < "&&DATE&M"D);
  Data selection based on the where clause.
  &CHART &VERT*DATE / SIGMAS=3 NOCHART
  INTERVAL=&INT
  OUTHISTORY=HIST&I OUTPHASE="&&PH&I"
  OUTLIMITS=LIM&I OUTINDEX="&&PH&I";
```

Calling the chart statement and defining the labels for the phase and index as created in the macro PHASE.

```
ID COMMENT;
Used to annotate the out-of-control point.
RUN;
```

```
DATA LIM&I; SET LIM&I;
  CALL SYMPUT('ULIMIT', _UCLI_);
  CALL SYMPUT('LLIMIT', _LCLI_);
  CALL SYMPUT('SIGMA', _STDDEV_);
  CALL SYMPUT('MEAN', _MEAN_);
  RETAIN; RUN;
```

This data step is used to create macro variables to test in the next data set for observations that are outside the upper and lower control limits to reestablish new control limits that have eliminated observations that can have an assignable cause.

```
DATA REDO; SET D;
  WHERE ("&&DATE&I"D <= DATE < "&&DATE&M"D);
  IF (&LLIMIT - .5*&SIGMA) < &VERT <
    (&ULIMIT + .5*&SIGMA) THEN OUTPUT REDO;
Exclude the out-of-control observations.
```

```
DATA _NULL_; SET REDO;
  CALL SYMPUT('RECNT', _N_);
  RETAIN; RUN;
DATA _NULL_; SET HIST&I;
  CALL SYMPUT('HISTN', _N_);
  RETAIN; RUN;
%IF &RECNT < &HISTN %THEN %DO;
```

Count the observations in data sets REDO and HISY&I, compare them and if there are fewer observations in REDO, execute the SHEWHART@ again to reestablish the control limits for data set LIM&I.

```
PROC SHEWHART DATA=REDO;
  WHERE ("&&DATE&I"D <= DATE < "&&DATE&M"D);
  &CHART &VERT*DATE / SIGMAS=3 NOCHART
  INTERVAL=&INT
  OUTPHASE="&&PH&I"
```

```

OUTLIMITS=LIM&I OUTINDEX="&&PH&I";
RUN;
%END;
DATA LIM&I; SET LIM&I;
CALL SYMPUT('ULIMIT',_UCLI_);
RETAIN; RUN;

```

```

DATA HIST&I; SET HIST&I;
IF &VERT < &ULIMIT THEN COMMENT = ' ';
IF &VERT > (4*&SIGMA + &MEAN) THEN
  &VERT = (4*&SIGMA + &MEAN);
MINDATE = "&&DATE&I"D;
MAXDATE = "&&DATE&M"D;
NUM = &I;
CALL SYMPUT('HISTN',_N_);
RETAIN; RUN;
%END;

```

Variables **MINDATE** & **MAXDATE** will be used for which observations are to be used when the final chart is produced. These are used in conjunction with macro variable **BEGDATE**. If the value of **&VERT** is set to 4 times **&SIGMA** + **&MEAN** if the value exceeds it. This may help with the visual aesthetics of the chart.

When all the observations in the data set have been analyzed that are less than **&DATE_n**, PROC SHEWHART® is executed one more time for the observations greater than **%DATE_n**.

```

%IF &I = &N %THEN %DO;
  %LET K = %EVAL(&N-1);
  PROC SHEWHART DATA=D;
    WHERE DATE >= "&&DATE&I"D;
    &CHART &VERT*DATE / SIGMAS=3 NOCHART
      INTERVAL=&INT
      OUTHISTORY=HIST&I OUTPHASE="&&PH&K"
      OUTINDEX="&&PH&K";
  ID COMMENT;
  RUN;
DATA HIST&I; SET HIST&I;
IF &VERT < &ULIMIT THEN COMMENT = ' ';
IF &VERT > (6*&SIGMA + &MEAN) THEN
  &VERT = (6*&SIGMA + &MEAN);
MINDATE = "&&DATE&I"D;
MAXDATE = "&&DATE&M"D;
NUM = &I;
RETAIN; RUN;
%END;
%END;

```

```

DATA LIM; SET %LIMI;
Concatenate all the LIM&I data sets into data set LIM.

```

```

%LET DOSTART = 1;
DATA HIST; SET %HISI;
BEGDATE = "&&BEGDATE"D;
DOSTART = &DOSTART;
%IF &N <= 3 %THEN %DO;
  %LET DOSTART = 2;
IF MINDATE <= "&&BEGDATE"D < MAXDATE THEN DO;
  CALL SYMPUT('DOSTART',LEFT(TRIM(NUM)));
END;
IF MINDATE = MAXDATE AND MAXDATE < "&&BEGDATE"D THEN
DO;
MINDATE =.;
MAXDATE =.;
CALL SYMPUT('DOSTART',LEFT(TRIM(NUM-1)));

```

```

END;
%END;

%IF &N > 3 %THEN %DO;
IF MINDATE <= "&&BEGDATE"D < MAXDATE THEN DO;
  CALL SYMPUT('DOSTART',LEFT(TRIM(NUM)));
END;
IF MINDATE = MAXDATE AND MAXDATE < "&&BEGDATE"D THEN
DO;
MINDATE =.;
MAXDATE =.;
  CALL SYMPUT('DOSTART',LEFT(TRIM(NUM-1)));
END;
%END;
FORMAT MINDATE MAXDATE BEGDATE DATE7.;
RETAIN; RUN;

```

The program logic beginning at the **%LET DOSTART** statement is to define the relationship between then **&DATE_n** and then desired beginning plot observation as defined by the macro variable **&BEGDATE**.

The last observation in the data set **HIST** is to be annotated on the final chart. In order to annotate this point, the following logic is used:

```

DATA HIST ; SET HIST;
OBS+1;
DATA _NULL_ ; SET HIST;
CALL SYMPUT('OBS',OBS);
CALL SYMPUT('Y',PUT(&VERT,F4.2));
RETAIN; RUN;
DATA ANO1; SET HIST;
IF OBS = &OBS;
LENGTH TEXT $ 5
FUNCTION
STYLE $ 8
POSITION $ 1;
WHEN = 'A'; /* PLACE TEXT AFTER GRAPH IS DRAWN */
XSYS = '2'; /* HORIZ VALUES ARE DATA DEPENDENT */
YSYS = '2'; /* VERT VALUES ARE DATA DEPENDENT */
POSITION = '3';
FUNCTION = 'LABEL'; /* PLACE TEXT ON GRAPH */
COLOR = 'BLACK'; /* TEXT COLOR */
SIZE = 1.2;
X = DATE; Y = &VERT;
STYLE = 'COMPLEX';
TEXT = "&Y";
OUTPUT;

```

After all this is done, the final control chart is produced:

```

PROC SHEWHART HISTORY=HIST GRAPHICS LIMITS=LIM;
WHERE DATE >= "&&BEGDATE"D;
&CHART &VERT*DATE / NPANEL=480
  INTERVAL=&INT
  TYPE=ESTIMATE
  SIGMAS=3
  READLIMITS
  SEPARATE
  READINDEXES=(%DO I=&DOSTART %TO &K;
    "&&PH&I " %END; )
  READPHASES=(%DO I=&DOSTART %TO &K;
    "&&PH&I " %END; )
  PHASELEGEND
  PHASEREF
  ANNOTATE=ANO1
  NOXLABEL

```

```
NOLEG
NAME="MYNAME"
DES="MY DESCRIPTION"
/* DESCRIPTION IN GCAT */
/* TEST=1 */
TESTLAB=TESTINDEX
OUTLABEL=(COMMENT)
LTEST=2;
```

```
RUN;
```

```
%MEND;
```

REFERENCES

SAS/QC Software, Version 6, First Edition, Cary, N.C.,
SAS Institute, Inc. 1990

SAS/GRAPH Software, Version 6, First Edition, Cary,
N.C., SAS Institute, Inc. 1990

ACKNOWLEDGMENTS

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```

%LET DATASET = MYDATA;
%LET CHART = "TYPE OF SHEWHART CHART DESIRED";
%LET VERT = "PROCESS VARIABLE";
%LET DATE1 = 'FIRST DATE'; **** FORMAT '01JAN94'D;
%LET DATE2 = 'SECOND DATE'; **** FORMAT '01JAN94'D;
%LET DATE3 = 'THIRD DATE'; **** FORMAT '01JAN94'D;
%LET DATE4 = 'FOURTH DATE'; **** FORMAT '01JAN94'D;
%LET N = 4; **** NUMBER OF PHASES;

```

```

***** DEFINE NUMBER OF PHASES

```

```

%MACRO PHAS;
%DO I=1 %TO &N;
  PH&I
%END;
%MEND;

```

```

***** CREATE MACRO VARS FOR PHASES & INDEX;

```

```

%MACRO PHASE;
%GLOBAL J %PHAS;
DATA _NULL_;
%DO I=1 %TO &N;
  LENGTH CNT $ 1 PH&I $ 11 MDATE $ 5;
  %LET J = %EVAL(&I + 1);
  %IF &I < &N %THEN %DO;
    PH&I = LEFT(TRIM(PUT("&&DATE&I'D,MONYYS.))) || '-' ||
    LEFT(TRIM(PUT("&&DATE&J'D - 1,MONYYS.)));
    CNT = LEFT(TRIM(&I));
    CALL SYMPUT('PH' || CNT, PH&I);
  %END;
  %IF &I = &N %THEN %DO;
    J = &J;
    MDATE = PUT(TODAY(), MONYY.);
    PH&I = LEFT(TRIM(PUT("&&DATE&I'D,MONYYS.))) || '-' ||
    MDATE;
    CNT = LEFT(TRIM(&I));
    CALL SYMPUT('PH' || CNT, PH&I);
    RETAIN;
  %END;
%END;
RUN;
%MEND;

```

```

***** LIMITS MACRO
***** DEFINE THE FINAL LIMITS DATA SET

```

```

%MACRO LIM;
%DO I=1 %TO (&N - 1);
  LIM&I
%END;
%MEND;

```

```

***** HISTORY MACRO
***** DEFINE THE FINAL HISTORY DATA SET

```

```

%MACRO HIS;
%DO I=1 %TO &N;
  HIST&I
%END;
%MEND;

```

```

%MACRO SHEW(DSET=MONTH,INT=MONTH);

```

```

%PHASE; ***** CALL MACRO ...

```

```

%IF &INT = MONTH %THEN %DO;
  %LET BEGDATE = 01JAN90;
%END;

```

```

%IF &INT = WEEK %THEN %DO;

```

```

%LET BEGDATE = 01JAN93;
%END;

```

```

***** HIST, LIMITS, OUTINDEX & OUTPHASES FOR FINAL;
***** WHEN PHASES ARE PRESENT;

```

```

DATA D; SET &MYDATA;
***** SUBSET DATA AS REQUIRED *****;
COMMENT = ??????????;

```

```

%DO I=1 %TO &N;
%IF &I < &N %THEN %DO;
  %LET M = %EVAL(&I+1);

```

```

PROC SHEWHART DATA=D;
  WHERE ("&&DATE&I'D <= DATE < "&&DATE&M'D);
  &CHART &VERT DATE / SIGMAS=3 NOCHART
  INTERVAL=&INT
  OUTHISTORY=HIST&I OUTPHASE="&&PH&I"
  OUTLIMITS=LIM&I OUTINDEX="&&PH&I";

```

```

ID COMMENT;

```

```

RUN;
DATA LIM&I; SET LIM&I;
  CALL SYMPUT('ULIMIT', _UCL_);
  CALL SYMPUT('LLIMIT', _LCL_);
  CALL SYMPUT('SIGMA', _STDDEV_);
  CALL SYMPUT('MEAN', _MEAN_);
  RETAIN; RUN;

```

```

DATA REDO; SET D;
  WHERE ("&&DATE&I'D <= DATE < "&&DATE&M'D);
  IF (&LLIMIT - .5*&SIGMA) < &VERT <
    (&ULIMIT + .5*&SIGMA) THEN OUTPUT REDO;
DATA _NULL_; SET REDO;
  CALL SYMPUT('RECENT', _N_);
  RETAIN; RUN;

```

```

DATA _NULL_; SET HIST&I;
  CALL SYMPUT('HISTN', _N_);
  RETAIN; RUN;

```

```

%IF &RECENT < &HISTN %THEN %DO;
  PROC SHEWHART DATA=REDO;
  WHERE ("&&DATE&I'D <= DATE < "&&DATE&M'D);
  &CHART &VERT DATE / SIGMAS=3 NOCHART
  INTERVAL=&INT
  OUTPHASE="&&PH&I"
  OUTLIMITS=LIM&I OUTINDEX="&&PH&I";

```

```

  RUN;
%END;
DATA LIM&I; SET LIM&I;
  CALL SYMPUT('ULIMIT', _UCL_);
  RETAIN; RUN;

```

```

DATA HIST&I; SET HIST&I;
  IF &VERT < &ULIMIT THEN COMMENT = ' ';
  IF &VERT > (4*&SIGMA + &MEAN) THEN
    &VERT = (4*&SIGMA + &MEAN);
  MINDATE = "&&DATE&I'D";
  MAXDATE = "&&DATE&M'D";
  NUM = &I;
  CALL SYMPUT('HISTN', _N_);
  RETAIN; RUN;

```

```

%END;

```

```

%IF &I = &N %THEN %DO;
***** HIST, LIMITS, OUTINDEX & OUTPHASES FOR FINAL;
***** WHEN DATES ARE AFTER LAST PHASE DATE;

```

```

%LET K = %EVAL(&N-1);
PROC SHEWHART DATA=D;
  WHERE DATE >= "&&DATE&I'D";

```

```

&CHART &VERT*DATE / SIGMAS=3 NOCHART
      INTERVAL=&INT
      OUTHISTORY=HIST&I OUTPHASE="&&PH&K"
      OUTINDEX="&&PH&K";

ID COMMENT;
RUN;

DATA HIST&I; SET HIST&I;
  IF &VERT < &ULIMIT THEN COMMENT = ' ';
  IF &VERT > (6*&SIGMA + &MEAN) THEN
    &VERT = (6*&SIGMA + &MEAN);
  MINDATE = "&&DATE&I"D;
  MAXDATE = "&&DATE&M"D;
  NUM = &I;
  RETAIN; RUN;

%END;
%END;

*****
***** SET LIMITS DATA SETS ;
*****

DATA LIM; SET %LIM;

*****
***** SET HISTORY DATA SETS ;
*****

%LET DOSTART = 1;
DATA HIST; SET %HISI;
  BEGDATE = "&BEGDATE"D;
  DOSTART = &DOSTART;
  %IF &N <= 3 %THEN %DO;
    %LET DOSTART = 2;
  IF MINDATE < "&BEGDATE"D < MAXDATE THEN DO;
    CALL SYMPUT('DOSTART',LEFT(TRIM(NUM)));
  END;
  IF MINDATE = MAXDATE AND MAXDATE < "&BEGDATE"D THEN
  DO;
    MINDATE =.;
    MAXDATE =.;
    CALL SYMPUT('DOSTART',LEFT(TRIM(NUM-1)));
  END;
  %END;

  %IF &N > 3 %THEN %DO;
  IF MINDATE < "&BEGDATE"D < MAXDATE THEN DO;
    CALL SYMPUT('DOSTART',LEFT(TRIM(NUM)));
  END;
  IF MINDATE = MAXDATE AND MAXDATE < "&BEGDATE"D THEN
  DO;
    MINDATE =.;
    MAXDATE =.;
    CALL SYMPUT('DOSTART',LEFT(TRIM(NUM-1)));
  END;
  %END;
  FORMAT MINDATE MAXDATE BEGDATE DATE7.;
  RETAIN; RUN;

%PUT DOSTART = "&DOSTART";
PROC SORT DATA=HIST; BY DATE;

*****
***** ANNOTATE FOR LAST POINT ;
*****

DATA HIST ; SET HIST;
  OBS+1;
DATA _NULL_; SET HIST;
  CALL SYMPUT(OBS,OBS);
  CALL SYMPUT('Y',PUT(&VERT,F4.2));
  RETAIN; RUN;
DATA ANO1; SET HIST;
  IF OBS = &OBS;
  LENGTH TEXT $ 5
  FUNCTION

```

```

STYLE $ 8
POSITION $ 1;
WHEN = 'A'; /* PLACE TEXT AFTER GRAPH IS DRAWN */
XSYS='2'; /* HORIZ VALUES ARE DATA DEPENDENT */
YSYS='2'; /* VERT VALUES ARE DATA DEPENDENT */
POSITION='3';
FUNCTION='LABEL'; /* PLACE TEXT ON GRAPH */
COLOR='BLACK'; /* TEXT COLOR */
SIZE=1.2;
X=DATE; Y=&VERT;
STYLE='COMPLEX';
TEXT='&Y';
OUTPUT;

```

```

*****
***** PRODUCE FINAL SHEWHART CHART ;
*****

```

```

PROC SHEWHART HISTORY=HIST GRAPHICS LIMITS=LIM;
WHERE DATE >= "&BEGDATE"D;
&CHART &VERT*DATE / NPANEL=480
  INTERVAL=&INT
  HREF=01JAN94"D
  HREFLABEL=('SEE FOOTNOTE')
  TYPE=ESTIMATE
  SIGMAS=3
  READLIMITS
  SEPARATE
  READINDEXES=(%DO I=&DOSTART %TO &K;
    "&&PH&I " %END; )
  READPHASES=(%DO I=&DOSTART %TO &K;
    "&&PH&I " %END; )
  PHASELEGEND
  PHASEREF
  ANNOTATE=ANO1
  NOXLABEL
  NOLEG
  NAME="MYNAME"
  DES="MY DESCRIPTION"
  /* DESCRIPTION IN GCAT */
  /* TEST=1 */
  TESTLAB=TESTINDEX
  OUTLABEL=(COMMENT)
  LTEST=2;

```

```

RUN;

```

```

%MEND;

```

•