APL IN QUALITY BUSINESS MANAGEMENT

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BUSINESS MANAGEMENT

Companies monitor their processes so that they can identify actions that need to be taken. Measures such as monthly sales, expenses by category, inventory levels, days debt and computer service availability are recorded and reported.

This paper introduces the application of quality control techniques to help you determine whether a process needs intervention. You will want to identify when a short term fluctuation becomes significant, when a longer term trend appears and most important, determine what sort of action is appropriate.

There are many potential pitfalls in presentation techniques even when the correct information is being used. Some are mentioned, but are not the prime purpose of this paper. There are good examples in reference 1.

QUALITY IN BUSINESS MANAGEMENT

The application of quality control techniques will help with some of the traditional problems of reporting, for example:

- It is difficult to tell what to look at when a chart is too full of numbers (Figure 1), exception reporting will help (Figure 5). The concept of control lines will help with the identification of exceptions.
- A report that only shows the latest results (column 2 of Figure 2) does not tell you whether this is the usual position or an exception. Often a rolling average (column 3) is used for comparison. Control charts such as the cusum chart will put information in context.
- The planned or required level of the process need to be shown (column 4 of Figure 2). The viewer can determine whether the figures are acceptable.
- A page full of success stories can be good for morale but conceals issues that need attention. Reports and charts are often more meaningful if they count defects rather than successes. It is then much easier to identify the action needed to reduce the defects.

- Use of graphics to give an immediate and accurate impression of the situation. (Figure 3) Though they can equally confuse unless care is taken (Figure 4 and reference 1).

STATUS REPORT

	CM	CE	ACT	YTD	YTDP	DIFF	YEPL	OUTLOOK	TOGET
Branch 1	[illegible]	[illegible]	313	1300	[illegible]	114	1874	1504	204
Branch 2	332	487	333	1122	1025	97	1878	1083	[illegible]
Branch 3	444	430	290	1130	[illegible]	144	1784	1284	144
Branch 4	400	318	387	1118	[illegible]	120	1436	1228	111
Branch 5	522	504	381	1287	1155	132	2092	1775	480
Branch 6	332	486	387	1191	1088	106	1808	1138	32
Branch 7	370	374	329	1273	1165	108	1888	1549	270
Branch 8	485	308	153	920	854	88	1534	1307	387
Branch 9	893	309	125	1087	888	145	1884	1547	980
Branch A	925	902	308	1332	1189	133	2084	1488	153
Branch B	412	388	171	951	888	88	1980	1271	320
Branch C	585	440	287	1318	1283	55	2082	1709	391
Branch D	498	532	128	1108	1023	85	1878	1841	433
Branch E	352	412	302	1148	1084	62	1588	1281	113
Branch F	332	983	211	1084	1036	80	1770	1550	483
Branch G	510	417	381	1308	1208	102	1884	1377	[illegible]
Branch H	487	408	187	1088	1003	83	1730	1233	177
Branch I	814	380	215	[illegible]	1008	107	1788	1302	193

Figure 1. A chart full of numbers

The Month in Context

Machine	Availability	Rolling Average	Commitment
Branch 1	99.1%	98.6%	99%
Branch 2	98.7%	98.7%	99%
Branch 3	99.8%	99.8%	99%

Figure 2. Computing Services Availability Report

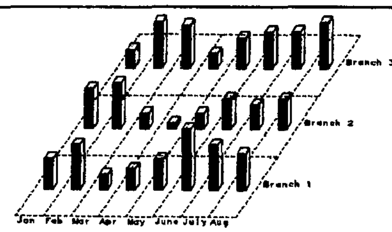


Figure 3. Graphics can help

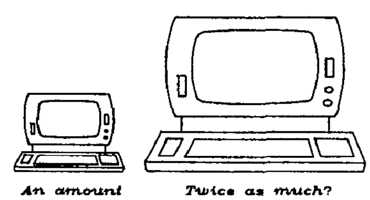


Figure 4. Graphics can be misused!

These are techniques that can be applied without great technical innovation. Deciding whether you have an exception and what sort of action should be taken is harder. For example:

- How different is the figure from what you would have expected? It may not be what you want, but is it sufficiently different from the past to trigger action?
- Is the process running at the required level? Even if the latest result is bad you could still be around the right level.
- Is there a change in the level of the process that *is significant? This is important whether* or not you are achieving the required level.
- Am I going to achieve target x by date y?

Changes may take several readings before you can be confident about them. This is where the principles of statistical quality control can help.

APL FOR QUALITY IN BUSINESS MANAGEMENT

To examine data I use VSAPL rel 4 with GDDM and GRAPHPAK (reference 2) for the graphics. This provides easy interactive facilities without a major investment in programming and without the formality of application packages. Once established, I use APE (reference 2) or the IBM PC to produce the required charts on regular basis. Within IBM I have access to internal software for statistics (GRAFSTAT, reference 9) and for chart production (APGS reference 3). An interactive statistics and graphics package is crucial for the development of ideas and techniques. The charts in this document and presented were produced using a generally available plotter with a roll of foil, or downloaded to a PC with a small plotter attached.

The APL code involved is not lengthy and would run in any APL environment. More attention would be needed to automate the collection of the data involved and in the special features of your graphics protocols.

THE MANAGEMENT SYSTEM

SUMMARY REPORTS

Although the examples shown have a weekly or monthly reporting cycle the same principles would apply to other frequencies. The subject of the report might be a list of computing services offered by a DP department (Figure 2). The measures might relate to the percentage availability or the number of interrupts that took place.

Following the advice above, you will highlight the unsatisfactory services. They may be unsatisfactory for a number of reasons. Where these are few and well known, they could be noted on the summary chart; where they are many then a supporting chart is essential.

March Service Availability

Machine	In Control	Level	Notes
Branch 1	A	-	Software
Branch 5	-	A	Project running
Branch A	W	-	

(A = out of control, W = 1 warning)

Figure 5. Computing Service Exception Report

Figure 5 shows a summary chart with one line for each service containing two control indicators and a comment space. The column 'in statistical control' tells us whether the level of service is consistent with the previous level of service. The column 'level' indicates whether the level of the service is meeting requirements.

The statistical methods used for quality control charts, described below, provide objective criteria for these columns. The notes indicate where any actions have been taken or are planned.

Whenever a service is identified as 'out of control' or 'not meeting requirements' then supporting information is required.

SUPPORTING INFORMATION

These are the foundations of the process. You will need to produce the 'supporting' information in order to produce the summary charts. Only the supporting charts that match an exception would normally be included in a reporting package.

It is now that you need to understand what is meant by in or out of statistical control. W.E. Deming (reference 4) pioneered much of the application of quality control to business management. Juran has produced textbooks (as reference 5) and education material on quality improvement.

As a general rule you should count defects, such as lost time, and aim to minimise them (Figure 6). An objective for each measure might thus be zero. In practice you may be rather far from an objective and choose to monitor against the current level, aiming to do better.

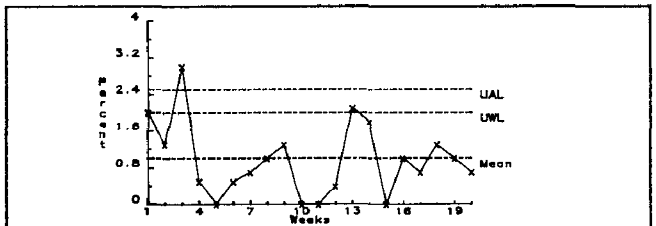


Figure 6. Non Availability of Service

In any process there will be ups and downs. You need to identify what degree of up and down should be expected. About 20 readings is usually sufficient to establish a level and the variability. Statistical theory can tell us how to calculate an expected variability. (See the appendix for some examples.)

If you are within that expected level then you should not be prompted to take any sudden action. Some processes have a clear pattern as in Figure 7 and it would not be sensible to panic at alternate readings! Others may be harder to tell, for example (Figure 8) when a process is increasing, when does a temporary reverse become a change in the rate of increase?

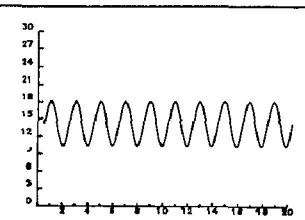


Figure 7. Alternating depression and rejoicing?

Fortunately you can use APL to apply statistical theory to indicate where there might be problems.

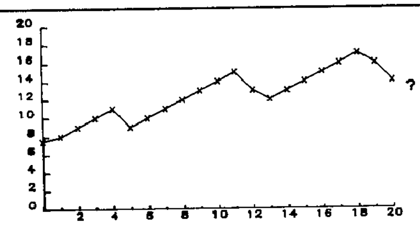


Figure 8. Short term change or start of the end?

STATISTICS

CONTROL CHARTS

A control chart is a line graph where you can plot the value of a process being monitored and identify the expected levels of variation. You can also identify significant changes in the process level itself. You should seek a proper description such as that in reference 5 section 23. Briefly:

P CHART A chart that monitors the proportion of defective items where you know the size of a fixed or variable sample. Figure 9

C CHART Charts that are used to monitor a count of defects where the count is much smaller than a possibly unknown population size. (Figure 10)

XBAR CHART Use to monitor the average of samples, or to plot an individual variable. (Figure 11)

RANGE CHART Associated with an Xbar chart to look at the variability within small samples (Figure 12).

CUSUM CHART A more sophisticated chart that uses the running total of the difference between a process and a fixed level. (Now you start to see the need for APL!.) It is particularly good at giving a visual image of changes in processes Figure 13

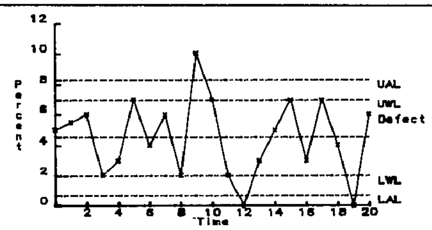


Figure 9. Orders not processed within 2 days

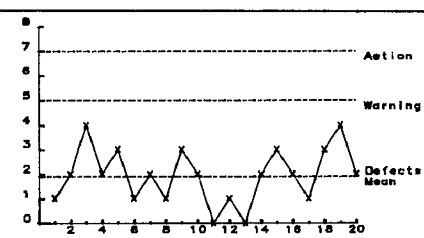


Figure 10. Number of software failures

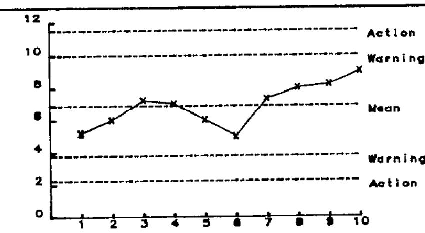


Figure 11. Average delivery time

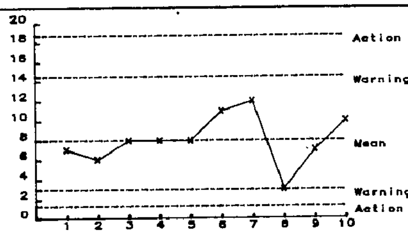


Figure 12. Range of delivery times

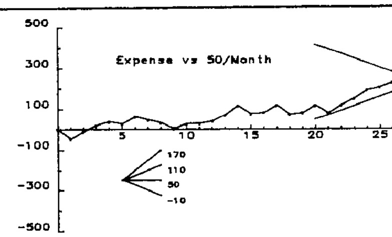


Figure 13. Monthly Expense vs Plan

A control chart that measures a process against a past level will tell you when a process is behaving differently from in the past. To examine whether it is achieving a specified target level, the control lines or cusum reference level should be the required level. Both were required for the exception report in Figure 5

CONTROL LINES

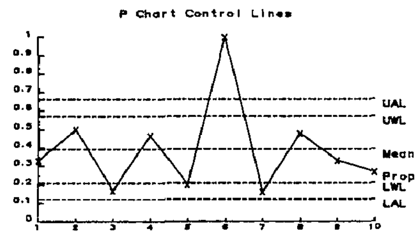
Apart from the CUSUM chart, you draw control lines that indicate warnings and action levels. As a general rule, when a process exceeds the warning line on two consecutive occasions, or the action line once then the process is said to be 'out of statistical control'. The level of these lines is calculated as the mean plus or minus a multiple of the standard deviation.

The standard deviation is calculated differently for the different types of data in the charts listed. The warning lines are the mean plus or minus twice the standard deviation, action lines are plus or minus three times the standard deviation. The appendix shows the sort of calculations needed. Figure 14 shows the calculation of control lines for a P chart.

```
∇LINES←SIZE PLINES DEFECT
⍝ Calculation of control lines for
⍝ P chart with constant sample size
P ← DEFECT÷SIZE
PBAR=(+/DEFECT)÷+/(⍴DEFECT)⍴SIZE
VAR←(PBAR×1-PBAR)÷⍴DEFECT
SDEV←VAR⋆.5
⍝ Action and warning lines and mean
LINES←PBAR+SDEV×¯3 ¯2 0 2 3
∇
```

Figure 14. Control lines for P charts.

For example, the number of days a service was not available 100% of the day as a proportion of the month would be plotted on a P chart. Figure 15assumes 30 days per month.




```
DEFECT←10 15 5 14 6 30 5 14 10 8
LINES←30 PLINES DEFECT
PLOT (DEFECT VS ⍳10) AND (2 5⍴LINES) VS 0 10
```

Figure 15. Using P chart control lines

The chart produced shows the data, upper and lower action and warning lines and a mean. When the lower lines are below the X axis they should be ignored. Most of the measures fall between the warning lines this indicates an 'in control process'. The sixth point however is out of control and some further investigation would be required.

The warning lines correspond to something that you might expect to happen naturally once in 40 readings and the action lines once in a thousand times.

Where you have the facilities to produce graphic output and the need to examine each measure this interactive approach is suitable. If you have many measures, you can identify whether each is in statistical control and then produce the charts for those that are not.

```
LINES←30 PLINES DEFECT
⍝ making use of global variables
⍝ in control if:
IN←(2×SDEV)∧.>|P-PBAR
⍝ 1 for warning 2 for action
SEV← +⌿(3 2×SDEV)∘.>|P-PBAR
```

Figure 16. Checking for in or out of control

For C charts, where there are a small number of defects compared to the number possible (but at least 5)· then SDEV is the square root of the average number of defects.

Although this technique allows you to look back in history and spotlight past problems, the more pressing need may be to look at the latest set of results and determine if action is needed. For a monthly review, it is helpful to plot weekly figures, for a weekly review plot daily figures if you can Figure 17

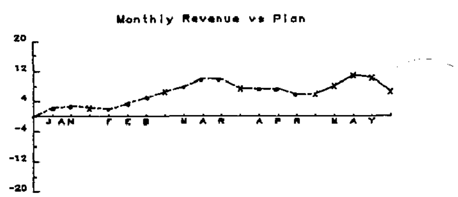


Figure 17. Weekly figures for monthly review

Based on, say a recent set of 20 readings you have established the control lines. You now add points for each new period and interpret the chart.

INTERPRETING THE CONTROL CHART

The recommended steps are:

1. Is the process in control with respect to the past level? If yes, go to step 5
2. Is it wildly out? If so investigate to establish the cause, do take action now, ignore other steps.
3. Is it drifting out? If so, the mean level may have changed so recalculate the control lines and re-evaluate from step 1. If there is a change that matters it will be detected at step 2 or 7.
4. Is the variation acceptable? A range chart can be produced that shows the variation within a sample. Control lines can be established for the range. An 'out of control' range could be wildly out or drifting, follow steps 2 and 3.
5. Is the process in control with respect to the target level? If so, go to step 7.
6. The target level is not being met. You now need to review it or take steps to improve the process as described in the next section.
7. The process is in control. You may now wish to look for any changes in the level. Examine the CUSUM by eye or replot against the previous level of the process to look for changes in level. You may not be happy with the variability and wish to take action to improve the level of the control lines.

IMPROVING THE PROCESS LEVEL

The mean level does not meet requirements? The variability is too great? You now have to identify the causes. A tool for this is the Ishikawa cause and effect diagram, often called the fishbone chart. (Figure 18 reference 8).

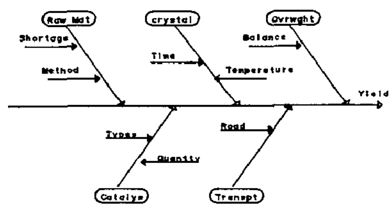
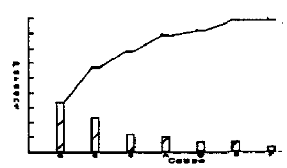


Figure 18. Ishikawa cause and effect chart

The objective is on the right, with the factors that affect it on the merging lines.

Having identified the potential causes, they must be ranked to identify the 'vital few' and the 'trivial many'. The 'pareto' technique is used for this. (A technique named by Juran, see reference 5, section 2.) Take each of the contibutory factors, put them in descending order and plot the cumulative value. Figure 19




```
CAUSE←'ABCDEFG'
AMOUNT←30 70 20 35 100 10 20
+\AMOUNT[⍒AMOUNT]
100 170 205 235 255 275 285
PLOT +\AMOUNT[⍒AMOUNT]
```

Figure 19. Pareto Chart

The 'Quality' approach (reference 8) would then suggest you initiate an improvement project for the vital few and use Quality Circles for addressing the others. A Quality Circle is a well defined forum where staff involved in a process meet weekly to diagnose and remedy problem areas.

THE CUMULATIVE SUM (CUSUM) CHART

DEFINITION

To look at the behaviour of a process compared with a reference level calculate the cumulative difference between the data and the reference level: "PLOT 0,+\DATA-LEVEL", The reference level may be a target level or the average over a recent period of about 20 readings. If you use the average of all the readings you have, "LEVEL ←(+/DATA)÷ρDATA" then the chart will always start and end on the X axis. When an individual reading is greater than the average the line will ascend, when it is less it will descend. The slope of the line is what is important.

CONTROL LINES

We are now concerned about the steepness of the slope so you have to draw a V shaped mask Figure 20The slope of the mask is determined by the standard deviation of the data. The mask is placed on the cusum at a point. If the cusum crosses the sides of the V the process is out of statistical control. This means that the process is running at a level significantly different from the reference level, or horizontal on the cusum chart.

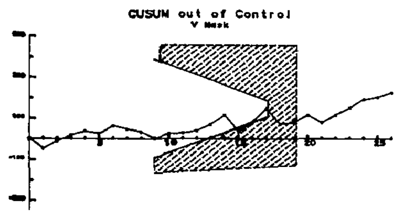


Figure 20. CUSUM with V mask

There is much theory about the best values for the mask, see reference 10 for a good introduction and reference 6 for discussion. In practice you should to scale the chart so that one unit on the X axis is physically the same as 2 standard deviations measured on the Y axis. See the appendix for how to calculate whether a point is in control.

THE PROTRACTOR

As noted above, the process starts and ends on the X axis. We can start to draw a protractor by labelling the horizontal as the mean value. Whenever the curve is level you are running at that value. Examination of the axes enables the construction of other values.

In Figure 21 you see the number of sales per month for 12 monthly results. The shape shows you were running at below average for 9 months and above average for 3. The average being 200, the level part is 200. To draw a 150 scale on the protractor you measure 1 unit horizontally and -50 vertically.

You can now use the protractor to measure the level of the process over any period by measuring the slope.

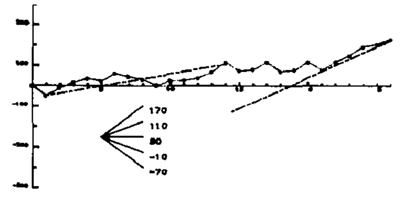


Figure 21. The CUSUM protractor

ACHIEVING AN OBJECTIVE

If you know you want to reach a specified objective, for example, a total number of sales or a percentage availability of a service, then you produce a CUSUM against the required level rather than the mean. Figure 22

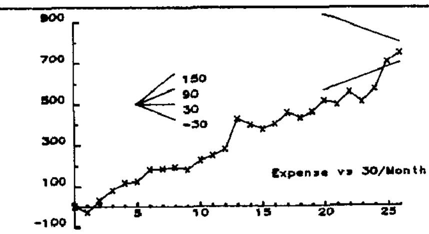


Figure 22. Is the target reasonable?

A curve which charges off in one direction is statistically out of control (will cut the V mask) and is a clear indication that the target is not reasonable! To see what has to be done to reach a target by a specified date, you have to measure the slope of the line required to return to the X axis in the specified time.

BUILDING THE MANAGEMENT SYSTEM

THE SOURCE

You should monitor processes in a way that action can be taken. Try to avoid compound indexes where it is not clear how the components are behaving. The numbers being monitored can come from existing files, such as from APLDI files, or recorded manually.

ANALYSIS

Depending on practicalities, you can produce the control charts and examine them manually, or compute whether they are in control and chart those that are not. (Use P, C, XBar-R or cusum charts)

An exception report might show those processes which have warnings and actions and processes that are not running at an acceptable level. It should not include processes that are in statistical control.

Notes are made where actions have been taken ... was there any effect? and where actions are going to be taken.

REPORTING

The exception reports you create will cause an immediate review of out of control situations; was action taken? will it stop a re-occurrence? is further action needed? (As in Figure 5 on page 4

Supporting charts will be required to explain those items out of control.

An in control process running at an unacceptable level might cause you to establish a project to improve the level. This would use the Ishikawa cause and effect chart to assess the causes and a pareto chart to rank them.

DEFINING THE TARGET LEVEL

A target could be expressed as a mean level over a period together with some control line criteria. For example a 98% availability over 4 weeks with no more than one day a month between 96% and 98% and 1 day every 3 years below 95%. If it is not acceptable to have days below 98%, then it is unreasonable to have a target process mean of 98%. The variability of the process will provide the necessary information to calculate the appropriate mean for a 98% warning line.

APL FUNCTIONS

CONTROL LINES FOR C CHARTS

```
   ∇LINES←CLINES DATA
 [1] CBAR←(+/DATA)÷ρDATA
 [2] SDEV←CBAR*.5
 [3] LINES←CBAR+¯3 ¯2 0 2 3×SDEV
   ∇
```

C CHART WITHOUT GRAPHICS

```
   ∇INTERRUPTS
 [1] ⎕←'Enter interrupts per day'
 [2] INT←⎕
 [3] ⍝ Want upper C chart lines
 [4] LINES←3↓CLINES INT
 [5] ⍝ 1 for warning 2 for action
 [6] COUNT←LINES+.<INT
 [7] MESSAGE←3 4ρ'OK  WARNACT '
 [8] (⍕((ρINT),1)ρINT),MESSAGE[COUNT;]
   ∇
```

CONTROL LINES FOR XBAR CHARTS

The control lines are still 2 and 3 times the standard deviation. This time the standard deviation of the XBAR values (SX) has to be calculated from the samples. For samples of 2 to 10 you can use a factor and the mean range. For equal samples in rows of X:

```
 R←(+/(⌈/X)-(⌊/X))÷N←1↑ρX
 A←.886 .590 .485 .43 .395 .37 .351 .337 .325
 SX←A[N-1]×RBAR÷N*.5
 LINES←(+/,X÷×/ρX)+SX×¯2 ¯1 0 1 2
```

CONTROL LINES FOR CUSUM CHARTS

Assuming that the cusum chart is correctly scaled, a V mask drawn on clear film can be used for different charts. There is a much theory on V masks (reference 7). A fairly standard mask is shown in Figure 23

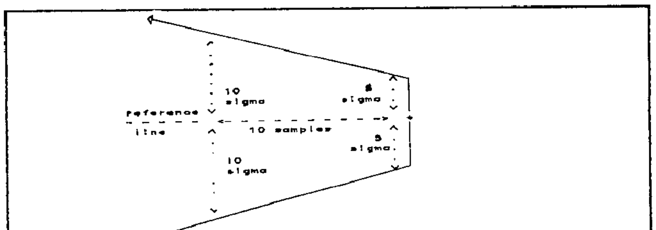


Figure 23. dimensions of a V Mask

The control lines on an X-bar chart are equivalent to the V mask on a cusum chart.

CUSUM IN OR OUT OF CONTROL

As you are interested in how many points on the chart cross the Vmask you can calculate the limits for the last N readings by adding fixed amounts to the point being considered and checking to see if the boundaries have been exceeded:

For point X,Y if the snub is 5 sigma, the starting levels are X, Y+(1 ¯1)×5×SIGMA. For a slope of 5 sigma over 10 readings I check the Y value of point X-1 against Y+(1 ¯1)×5.5×SIGMA. Figure 24shows the calculation of points that would be outside the VMASK. Once a process is established, you would only look at the latest value - a much simpler calculation.

```
      ∇ CUSUM X
 [1]  ⍝ setup
 [2]   IND←⍳ρX
 [3]  ⍝ points to be tested against earlier points
 [4]   VALID←IND∘.>IND
 [5]  ⍝ calculate mean and standard deviation
 [6]   MEAN←+/X÷ρX
 [7]   SIGMA←((+/((¯1↓X)-1↓X)*2)÷2×¯1+ρX)*0.5
 [8]  ⍝ calculate cusum
 [9]   XC←+\X-MEAN
 [10] ⍝ Diffs between CUSUMs vs what is allowed
 [11]  ACT←|VALID×XC∘.-XC
 [12]  ALL←|VALID×SIGMA×5+.5×IND∘.-IND
 [13]  COUNT←(0,IND)[1+(ACT>ALL)×(2ρρX)ρIND]
 [14] ⍝ Report results
 [15]  (0⍕X,[1.5] XC),':',⍕COUNT
      ∇
  ⍝ look at ⍳10, sdev is small
      CUSUM ⍳10
   1  ¯4: 0 0 0 0 0 0 0 0 0 0
   2  ¯8: 1 0 0 0 0 0 0 0 0 0
   3 ¯10: 1 0 0 0 0 0 0 0 0 0
   4 ¯12: 1 0 0 0 0 0 0 0 0 0
   5 ¯12: 1 0 0 0 0 0 0 0 0 0
   6 ¯12: 1 0 0 0 0 0 0 0 0 0
   7 ¯10: 1 0 0 0 0 0 0 0 0 0
   8  ¯8: 0 0 0 0 0 0 0 0 0 0
   9  ¯4: 0 0 3 4 5 6 7 0 0 0
  10   0: 0 2 3 4 5 6 7 8 9 0

 ⍝ Which shows that 2-9 are outside the
 ⍝ VMASK for point 10.

      MEAN
 5.5
      SIGMA
 0.7071

      1⍕XC
 ¯4.5 ¯8 ¯10.5 ¯12 ¯12.5 ¯12 ¯10.5 ¯8 ¯4.5 0
```

Figure 24. Finding the out of control triggers

BIBLIOGRAPHY

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