

CUSUM FOR THE CONTROL OF VIBRATION AND AIR BLAST

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ABSTRACT

Cumulative sum (CUSUM) statistical process control methods have been used in many industries to monitor quality control results. CUSUM charts are a method to determine when small changes in data indicate a major change in results. E.S. Page at AT&T developed the method in 1954.

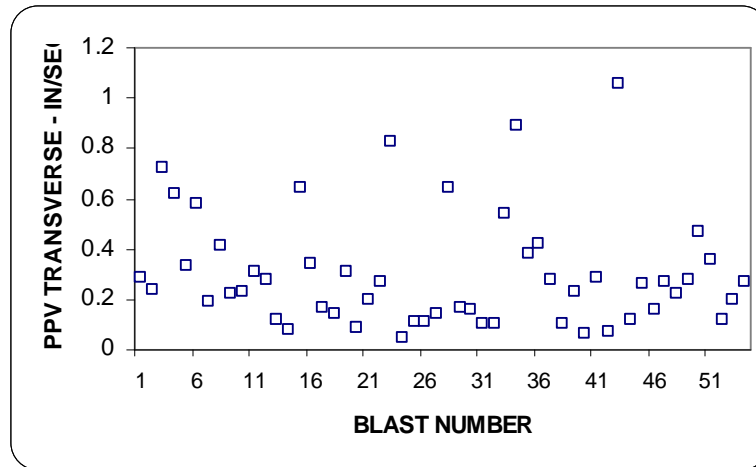
In many blasting situations, vibration and air blast readings vary slightly from blast to blast. Whether the change is significant or not can be hard to interpret from the raw data. CUSUM charts can assist in determining whether a major change is taking place and when the change began.

While CUSUM charts do not directly give causal information about the vibration and air blast changes, they can be used with other techniques to determine why change is occurring. In particular, CUSUM charts of the main variables affecting vibration and air blast can be married with the results to help explain changes. The ability of CUSUM charts to highlight the timing of changes is important when changes are made.

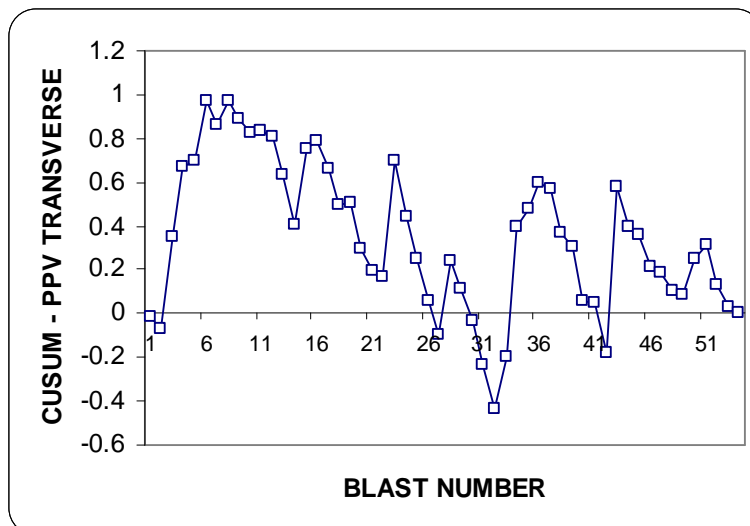
CUSUM charts are easy to implement and the visual results are helpful to interpret changes. The authors believe that CUSUM charts will be used also to explain changes in other mining variables such as productivity and size generation in the future.

INTRODUCTION

Vibration and air blast results can be hard to interpret as to whether blast timing and blast design changes are improving or worsening the overall results. Geology and environmental conditions are so variable that they can mask the general trend of results and a blaster may be confused as to whether his efforts are working or not. For example, below is a chart of vibration readings at a mine for 54 consecutive blasts. While the readings are all acceptable, because of the spikes and noise in the data it is hard to determine whether efforts are improving or degrading results. Have changes in timing or blast design made a major change or is it an anomaly?



A CUSUM chart of the same data gives a better picture and can increase confidence that the changes that are improving the situation. The slope of the data indicates whether conditions are improving or degrading. The timing of a change is highlighted. For example, a change was made from blast 7 on and the slope of the CUSUM curve highlights the results decreasing PPV. Similarly, changes from blast 33 to 37 increased PPV. The overall downward slope of the curve indicates continuous improvement. The short upward increases indicate a quick response to problems.



HOW IS A CUSUM CHART PRODUCED?

Cumulative sum (CUSUM) statistical process control methods have been used in many industries such as manufacturing, pharmaceuticals, cement, and medicine to monitor quality control results. One of the most common CUSUM approaches is the PAR rating in golf. A golfer can keep track of how well he is playing by how much he is above or below PAR during a round of golf. The PAR system is a cumulative sum of the differences at each hole.

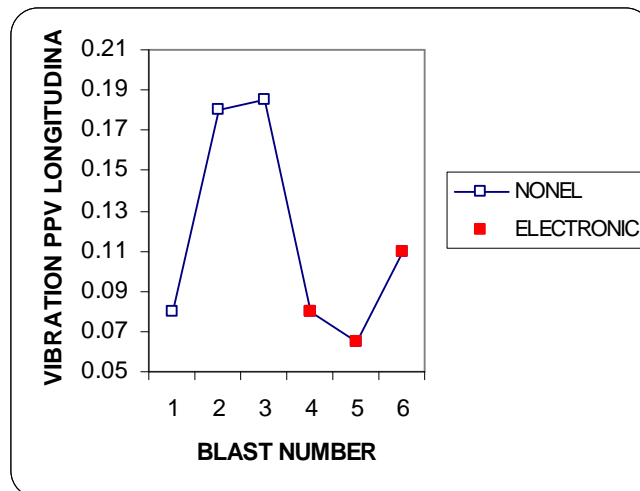
CUSUM charts are a method to strengthen signals to determine when small changes in data indicate a major structural change in results. The method was developed in 1954 by E.S. Page at AT&T to improve manufacturing process quality control.

SIMPLE CUSUM CHART EXAMPLE

A quarry is introducing an electronic blasting system and is attempting to determine whether electronic initiation is effecting vibration reduction.

BLAST NUMBER	INITIATION SYSTEM	LONGITUDINAL PPV - IN/SEC
1	NONEL	0.080
2	NONEL	0.180
3	NONEL	0.185
4	ELECTRONIC	0.080
5	ELECTRONIC	0.065
6	ELECTRONIC	0.110

The following chart of the above data of the longitudinal vibration from 6 blasts is not conclusive and further evidence is desired.



The method to develop a CUSUM chart is relatively easy.

1) Starting with an EXCEL spreadsheet as shown above, an average of the PPV data is calculated.

BLAST NUMBER	INITIATION SYSTEM	LONGITUDINAL PPV - IN/SEC
1	NONEL	0.080
2	NONEL	0.180
3	NONEL	0.185
4	ELECTRONIC	0.080
5	ELECTRONIC	0.065
6	ELECTRONIC	0.110
		0.117 =AVG LONGITUDINAL PPV FOR BLASTS 1 THROUGH 6

2) The average PPV is subtracted from each actual PPV.

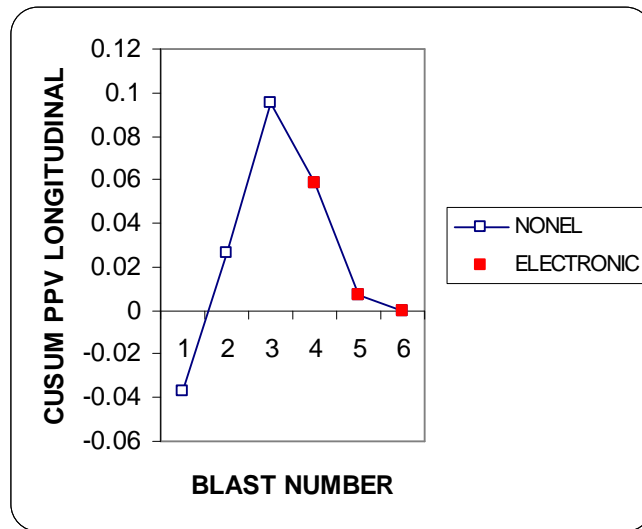
BLAST NUMBER	INITIATION SYSTEM	LONGITUDINAL PPV - IN/SEC	ACTUAL PPV MINUS AVERAGE
1	NONEL	0.080	.080 - .117 = - 0.037
2	NONEL	0.180	.180 - .117 = + 0.063
3	NONEL	0.185	.185 - .117 = + 0.068
4	ELECTRONIC	0.080	.080 - .117 = - 0.037
5	ELECTRONIC	0.065	.065 - .117 = - 0.052
6	ELECTRONIC	0.110	.110 - .117 = - 0.007
		AVG=	0.117

3) The actual minus the average PPV values are then accumulated to produce the CUSUM data.

BLAST NUMBER	INITIATION SYSTEM	LONGITUDINAL PPV - IN/SEC	ACTUAL PPV MINUS AVERAGE	CUSUM
1	NONEL	0.080	-0.037	-0.037
2	NONEL	0.180	0.063	-0.037 +0.063 = 0.027
3	NONEL	0.185	0.068	+0.027+0.068 = 0.095
4	ELECTRONIC	0.080	-0.037	+0.095 -0.037 = 0.058
5	ELECTRONIC	0.065	-0.052	+0.058 -0.052 = 0.007
6	ELECTRONIC	0.110	-0.007	+0.007 -0.007 = 0.000
		AVG=	0.117	

4) The final spreadsheet below is graphed:

BLAST NUMBER	INITIATION SYSTEM	LONGITUDINAL PPV - IN/SEC	ACTUAL PPV MINUS AVERAGE	CUSUM
1	NONEL	0.080	-0.037	-0.037
2	NONEL	0.180	0.063	0.027
3	NONEL	0.185	0.068	0.095
4	ELECTRONIC	0.080	-0.037	0.058
5	ELECTRONIC	0.065	-0.052	0.007
6	ELECTRONIC	0.110	-0.007	0.000
AVG=		0.117		

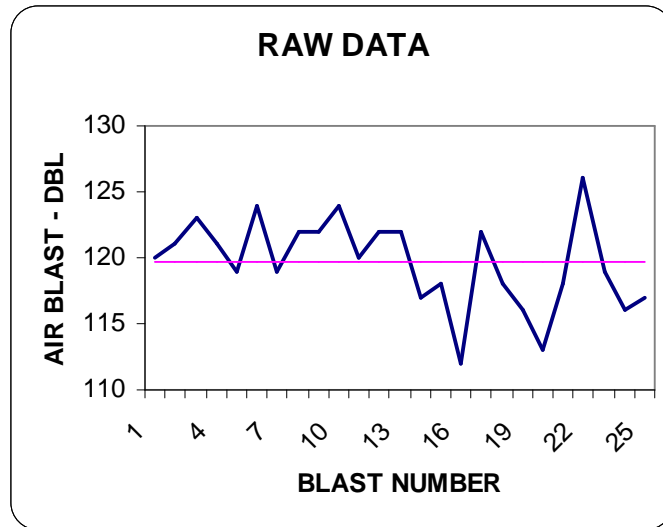


When trying to interpret a CUSUM chart remember that the slope is important not the individual data. A change in slope direction indicates when change was initiated. In this example, PPV slope with conventional nonelectrics is increasing and the slope with electronic initiators is decreasing (indicating improvement). Since most blasting results are the result of multivariable causes, a CUSUM chart doesn't always give the reasons for changes. However, a vibration or air blast CUSUM chart can be used with CUSUM charts of critical blasting variables such as distance, scaled distance, lbs per delay, stemming, etc. to determine causes of change. There are advanced masks and multivariate techniques to be used with CUSUM analysis but those are not in the scope of this paper. The following Air Blast example will develop this technique further.

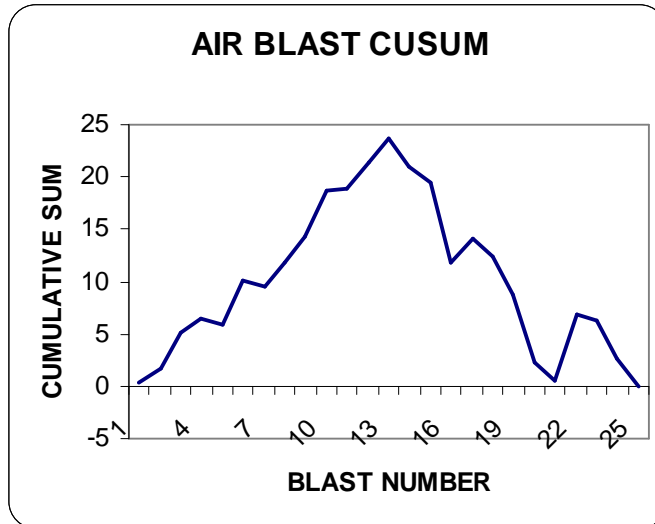
AIR BLAST EXAMPLE

To understand how CUSUM can help determine the cause of air blast changes the following example will illustrate the technique. Below is the raw data from several blasts indicating air blast level in DBL. Also shown is the average value for reference. As in the previous example, the raw data is hard to interpret to determine whether changes are improving or degrading the results.

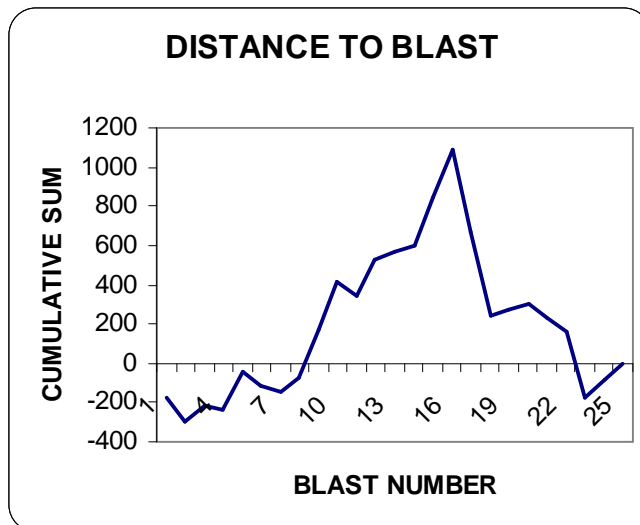
BLAST NUMBER	TEMPERATURE F	WIND SPEED DIRECTION	AIR BLAST DB	DISTANCE - FT SEISMOGRAPH	NUMBER HOLES	MAX FACE HEIGHT	MINIMUM STEMMING	MINIMUM BURDEN	MINIMUM SPACING	MAXIMUM LB/DELAY	POWDER FACTOR TONS/LB	SCALED DISTANCE
1	90	5W	120	1161	14	61	13	22	12	900	1.60	38.7
2	80	15W	121	1214	24	61	13	22	12	900	1.47	40.5
3	80	10W	123	1425	33	58	13	22	12	900	1.40	47.1
4	85	5W	121	1320	30	61	12	22	12	900	1.50	44.2
5	85	5W	119	1531	28	58	12	22	12	900	1.45	51.5
6	80	CALM	124	1267	33	62	12	20	12	925	1.41	41.6
7	70	5S	119	1310	33	62	12	20	12	950	1.59	42.5
8	70	5W	122	1405	24	63	13	20	12	1075	1.45	43.5
9	60	20S	122	1584	35	62	13	20	12	902	1.47	52.7
10	42	10W	124	1584	28	65	13	14	17	899	1.56	52.8
11	50	10SW	120	1267	32	60	15	20	12	716	1.56	47.3
12	40	5W	122	1531	29	62	13	20	12	855	1.37	53.3
13	40	5W	122	1372	18	62	13	20	13	900	1.67	45.7
14	40	5W	117	1372	18	62	13	20	13	900	1.67	45.7
15	45	10SE	118	1584	21	70	13	20	13	1200	1.87	45.7
16	45	10SE	112	1584	21	70	13	20	13	1200	1.87	45.7
17	48	10W	122	915	32	65	13	20	13	950	1.43	29.7
18	48	10W	118	915	32	65	13	20	13	950	1.43	29.7
19	70	5W	116	1372	26	77	12	22	12	1100	1.45	41.4
20	70	5W	113	1372	26	77	12	22	12	1100	1.45	41.4
21	60	5W	118	1267	24	64	12	20	13	900	1.54	42.2
22	60	5W	126	1267	24	64	12	20	13	900	1.54	42.2
23	80	5W	119	1003	35	49	13	20	13	726	1.50	37.2
24	90	5W	116	1425	20	70	13	20	12	975	1.60	45.6
25	90	5W	117	1425	20	70	13	20	12	975	1.60	45.6



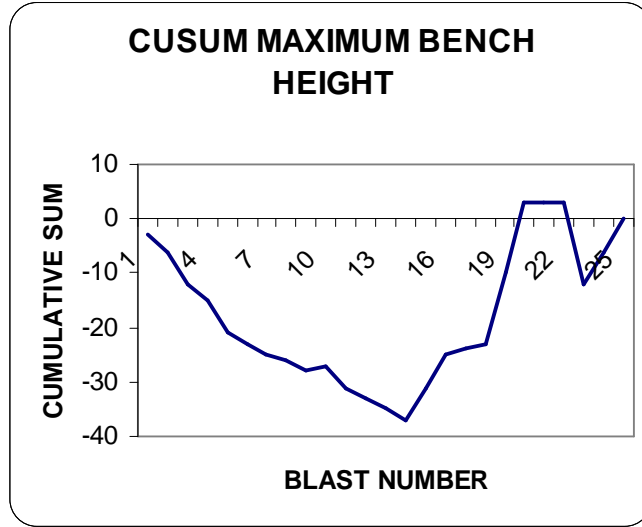
A CUSUM chart is generated using the techniques developed in the vibration example above. The CUSUM chart indicates that air blast levels began decreasing at Blast Number 14.



A series of CUSUM charts are produced of each of the variables affecting air blast such as distance, charge per delay, temperature, maximum bench height, stemming length, etc. For example below is the CUSUM for distance to the blast. While distance is important note that the peak is at blast 17, not blast 14 as in the Air Blast CUSUM.



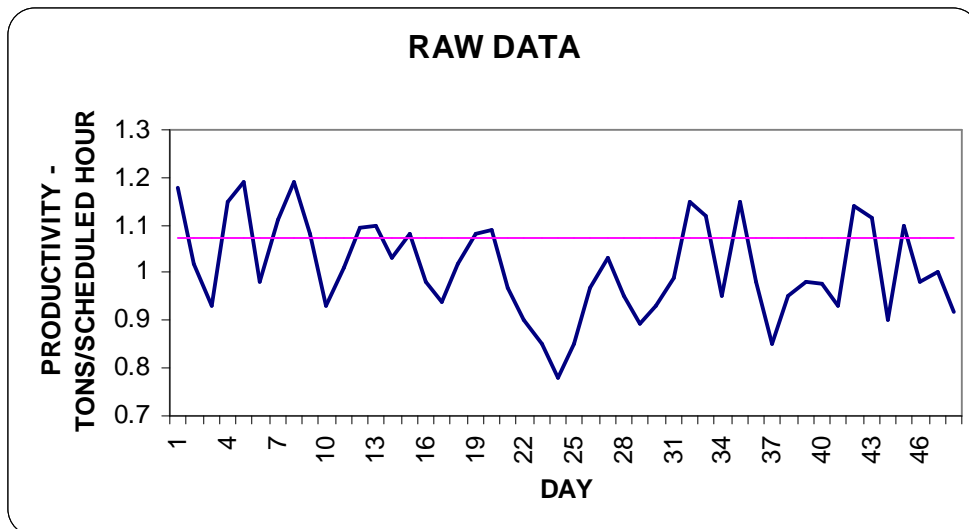
The variable that indicates a change in slope at Blast 14 similar to the CUSUM chart for air blast is the responsible variable. In this example it is maximum bench height with the air blast increasing as maximum bench height is reduced. Note, the actual values are meaningless and only the change in slope is important.



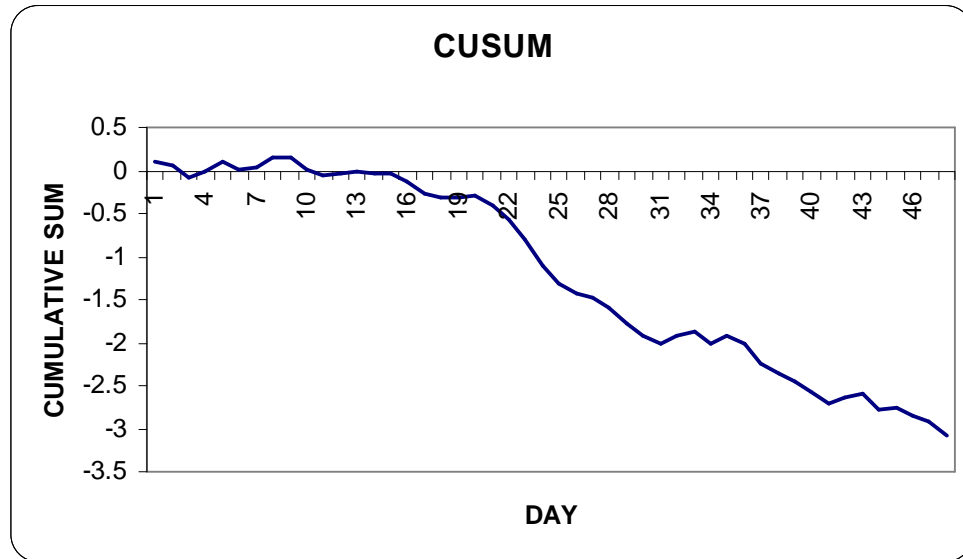
THE FUTURE

The authors believe that these techniques can be helpful in determining the results of changed blasting designs and procedures on vibration and air blast in particular and could be extended to mining productivity and aggregate size optimization in the future. CUSUM techniques can enhance the multivariate regression analysis information being used presently to determine the drivers of vibration, air blast, productivity, and other explosives related mining variables.

For example, in the early 1980's in developing ways to optimize productivity one of the authors had optimized a mine as shown below – the red line indicates the average after optimization.



Because of another mine optimization program which was wildly successful, the author changed the pattern at day 21 even though not indicated in the original mine data. The pattern area was the same and the assumption, which was wrong, was that it would increase productivity further. After continuing for 120 days it was finally recognized that the wrong decision was made and it was reversed. Below is a CUSUM analysis that would have identified the change much sooner.



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