COMPARATIVE STUDY OF CUSUM WITH V-MASK AND EWMA CONTROL CHARTS FOR STRENGTH MONITORING OF READY MIXED CONCRETE

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ABSTRACT

Control charts are tools of Six-Sigma framework, extensively used for the quality monitoring in several manufacturing and production units. These charts are one of the finest tools for quality management practices worldwide. X-Bar-S and X-Bar-R charts are currently in practice for the purpose of quality monitoring, but these charts fail to detect the small shifts in the mean. Therefore, either these charts need more sensitizing tools or the charts with some special power like Cumulative Sum (CUSUM) charts or Exponentially Weighted Moving Average (EWMA) charts have to be used for the detection of small shifts as the standard deviation observed in the plants for case study is not very high. At present, Ready-Mixed Concrete (RMC) industry follows limited number of quality control tools that are offline. This makes the fresh concrete, which is the end-product of the concrete manufacturing plant vulnerable to too many uncontrollable and unassignable external factors. This paper is an attempt to compare the two techniques CUSUM and EWMA and generate a desirable output that is useful to the RMC industry in strength monitoring and Mix-Design modification. These techniques would help commercial RMC plants to produce superior quality concrete in comparatively lesser costs.

Keywords: CUSUM, EWMA, Ready Mixed Concrete, Root Cause Analysis, Strength Monitoring

I. INTRODUCTION

Control charts are an important tool for the monitoring of quality in general. X-Bar charts in conjunction with either Range charts or Standard Deviation charts, are used to control the process mean and the process variability. However, the problem of the X-Bar-S and X-Bar-R chart lies in not detecting accurately the small shifts. The interpreting run-chart rules of these charts also change depending on the industry. Therefore, CUSUM and EWMA charts are of significance as they readily detect the small shifts with unique distinctive approach. Both of these charts are also widely used as multivariate charts. Only specific industries opt these charts. CUSUM charts takes all the previous values in to the consideration, and then a V-Mask, is designed in accordance to it to check the validity of the CUSUM values. In CUSUM with V-Mask charts, the point moving outside the control limits or the V-mask is not the actual sample with defect; the mean may have already shifted. The actual point of action is not the out of control point. The point of action may be well within the control limits, which may be difficult to track. In the EWMA charts, the parameters of L and lambda (λ) are set in a way that the samples directly correspond to the point of action and the root-cause-analysis is easy to perform.

The basic objective is that the high quality provided to the customer should directly affect the baseline of the organization by financial gains, direct short term and long term profits by brand building. At present, the quality management practices followed in Ready-Mixed Concrete industry lack online monitoring. The quality monitoring practices are restricted to computation of standard deviation and process control methods that are not statistical. Statistical Quality Monitoring gives a significant amount of statistical details for the collected information. One of the advantage of statistical quality monitoring is that the statistical data can be analyzed or diagnosed for the trend analysis and minor adjustments can be made in very short time as the process is known. Advantages of statistical monitoring also includes less internal failures, cost saving by having increased plant and staff productivity resulting in reduced operating costs and enhanced profitability. The application of control charts in RMC industry is not still openly established to be favorable for the overall business. Owners face the dilemma of making a decision of whether or not to utilize the benefits of control charts, as it requires skilled and trained human resource.

Present day, RMC industry has a huge potential to grow in the construction sector. Poor management practices and lack of any statistical quality control has resulted in inconsistent quality, higher production costs and disorganized use of raw materials. Cement – a material that has very high impact on concrete strength is also poorly managed accounting to a substantial amount of higher production costs. Cement being one of the prime materials for concrete making is placed the under high impact and high control under the material management matrix. Major factors affecting the poor quality of concrete are: limited amount of goods, incomplete infrastructure and inadequate knowledge (Juran and Gryna 1988) out of which the second is one of the prime factor in India. Optimization of quality is the prime objective to save the production cost of concrete.

II. LITERATURE REVIEW

[1] Alhozaimy and Al-Negheimish (1999) pioneered the concept of managing quality scheme for RMC. They focused upon the aspects of Economy and Quality Assurance by the technique of Total Quality Management (TQM) and quantified the benefits of improving the quality of concrete. Tangible benefits were achieved in all aspects of RMC production and quality.

[2]Sarkar and Bhattacharjee (2014) & [3]Sarkar & Dutta (2011) have applied CUSUM technique with V-Mask and Risk Adjusted Cumulative Sum (RACUSUM) model respectively. RACUSUM model is assumed to have higher degree of sensitiveness than conventional CUSUM model for monitoring the strength of the available grades of concrete produced by commercial and in-house batching plants. Sarkar & Bhattacharjee also considered additional major parameters which contributed for producing a superior quality concrete and developed a model which can simultaneously monitor the quality of RMC. This model was multivariate CUSUM where 3 to 4 parameters governing the quality like slump, density, 7-day cube compressive strength, 28-day cube compressive strength were considered at the same time for monitoring the quality of RMC.

[4]Sullivan (2011) focused on competitiveness by increasing performance in the construction industry. He analyzes three popular programs (total quality management (TQM), lean production, and six sigma), for the suitability of implication in construction.

[5]Beary & Abdelhamid (2005) successfully applied the Lean production and Six Sigma principles for the residential projects using the DMAIC process. They introduced a production planning model that reduces variations and defects (muda and mura), and creates a reliable production planning system.

[6]Han et al (2008) attempted to improve performance in construction process using six-sigma by applying new philosophies such as lean principle, just-in-time, pull scheduling, and last planner. They explored practical solutions for construction performance improvement by applying the six-sigma principles.

III. CASE STUDY

The case studies considered for this research work are two commercial batching plants in Gandhinagar and Ahmedabad region of Gujarat, India. The sample size taken here is of 30 samples. Each sample is the mean of 3 observations of compressive strengths at the end of 28 days as observed during the experiments.

3.1 CASE STUDY 1:

This batching plant in Gandhinagar is of capacity 30 cubic meter per hour. It works in-house as well as commercially. Two silos of capacity 1.5 tons each are present at the plant for the storage of cement and fly-ash respectively. The coarse aggregates and fine aggregates are loaded with the help screw-conveyer. The source of coarse aggregate and fine aggregates is Gandhinagar and Sabarkantha respectively. Water dispenses with the help of over-head water tank and admixtures dispense with the help of dispensing machine. The typical grades of concrete produced ranges from M-7.5 to M-80. Here “M” stands for the design mix and “7.5” stands for the typical characteristic concrete cube compressive strength at the end of 28 days. The plant is fully automatic. The Table 1 below shows the collected data for M-25 grade concrete from June 2nd, 2015 to July 19th, 2015 as CASE 1.

3.2 CASE STUDY 2:

This commercial batching plant in Ahmedabad is of capacity 30 cubic meter per hour. This plant has two silos of capacity 1.5 tons each for the storage of cement and fly-ash respectively. The coarse aggregates and fine aggregates are loaded with the help screw-conveyer. The source of coarse aggregate is Gandhinagar and the source of fine aggregates is Sabarkantha. Water is dispensed with the help of over-head water tank and admixtures are dispensed with the help of dispensing machine. The typical grades of concrete produced ranges from M-15 to M-50. Here “M” stands for the design mix and “15” stands for the typical characteristic concrete cube strength at the end of 28 days. The plant is fully automatic. The given below – Table 1 shows the collected data for M-25 grade concrete from August 5th 2015 to October 10th 2015 as CASE 2.

International Journal of Advanced Technology in Engineering and Science
Vol. No.5, Issue No. 01, January 2017
www.ijates.com
ijates
ISSN 2348 - 7550

TABLE 1: CASE 1 CONCRETE FOR M25 FOR BOTH THE PLANTS

	CASE 1		CASE 2	
Sample No.	7 Day Compressive Strength	28 Day Compressive Strength	7 Day Compressive Strength	28 Day Compressive Strength
1	22.88	31.80	23.42	33.08
2	23.45	32.50	23.92	33.78
3	22.84	32.17	23.70	33.45
4	21.74	31.05	22.93	32.33
5	22.89	32.24	23.77	33.52
6	24.85	33.83	24.89	35.11
7	21.55	31.30	23.13	32.58
8	23.31	33.27	24.52	34.55
9	22.34	31.96	23.61	33.24
10	22.98	32.34	22.10	31.06
11	22.86	32.00	21.87	30.72
12	23.20	33.08	22.64	31.80
13	22.72	31.43	21.49	30.15
14	22.94	31.94	21.86	30.66
15	21.85	31.34	21.45	30.06
16	21.84	31.19	21.36	29.91
17	22.25	32.03	21.95	30.75
18	22.84	32.14	22.04	30.86
19	22.24	31.77	21.79	30.49
20	23.62	32.39	22.24	31.11
21	22.49	32.20	22.56	31.56
22	22.41	32.09	22.49	31.45
23	23.83	32.49	22.78	31.85
24	26.54	35.39	24.82	34.75
25	22.99	31.79	22.31	31.15
26	22.40	31.71	22.26	31.07
27	22.52	31.99	22.47	31.35
28	23.28	32.47	22.82	31.83
29	23.16	32.46	22.82	31.82
30	22.56	31.99	22.50	31.35

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ISSN 2348 - 7550

IV. ANALYSIS AND DISCUSSION:

Both the cases are analyzed with EWMA and V-mask cusum control charts. The statistic formula of both of the control charts is given below. The Exponentially Weighted Moving Averages are calculated based on the following equation [7] :

$z_i = \lambda x_i + (1-\lambda)\, z_{i-1}$... (1)

where, $0 < \lambda \leq 1$ is a constant and the starting value (required with the first sample at *i* = 1) is the process target; z_i is the smoothened value that is obtained by applying the statistical smoothening of Lambda (λ),

x_i is the sample number.

the Upper Control Limit (UCL) and Lower Control Limits (LCL) are calculated with the following formula:

$$UCL = \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \qquad (2)$$

$CL = \mu_0$

$$LCL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \qquad (3)$$

Here, L is a constant and Lambda (λ) is the constant as defined for equation (1).

CUSUM charts are of two types namely Tabular CUSUM and V-Mask CUSUM. The one that is used in this research paper is the V-Mask CUSUM control chart.

The V-Mask CUSUM chart incorporates the information in the sequence of sample values by plotting the cumulative sums of the deviations of the sample values from a target value calculated on the following equation

$$C_i = \sum_{j=1}^{i}(\bar{x}_j - \mu_0) \qquad (4)$$

Ci is called the cumulative sum up to and including the *i*th sample

$\bar{x}_j$ is the average of the *j*th sample

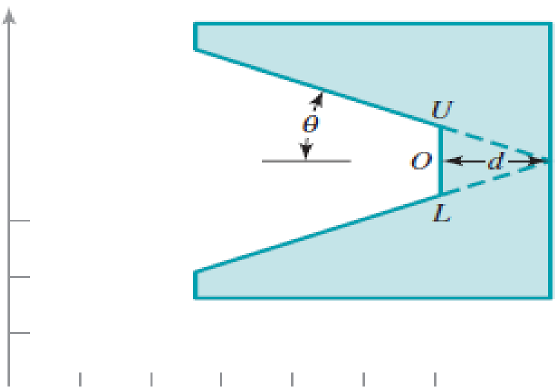

Figure 1: Design of V-Mask

μ_0 is the target for the process mean

V-mask is designed in a way that it encases the samples within the defined control limits. Here, in Fig 1;

U= Upper Control Limit (UCL)

L= Lower Control Limit (LCL)

d= Decision Interval

θ= the slope of the gradient

With the WMA, Smoothened value, UCL 1 and LCL 1 for EWMA chart and Deviation from mean, Cusum Value, UCL 2 , LCL 2 for V-mask cusum, the 28-day compressive strength data is analyzed and presented in a tabular form in Table:2 below.

For the EWMA control charts, L= 2 and Lambda (λ) = 0.2. These values are utilized to obtain the smoothened value and UCL 1 and LCL 1. Smoothened values are the average compressive strengths that are statistically modified with the factors of Lambda (λ) and L. CL in Fig-2 is the Centre-Line. It is the average of all the 30 samples. For the V-mask cusum chart, the decision interval (*d*) is taken to be 8.5 times the standard error (σ) and the gradient is taken to be σ/10.

TABLE:2 Chart for 28-day compressive strength for M25 grade of concrete

	EWMA CHART				CUSUM CHART			
Sample No.	WMA	Smoothened Value	UCL 1	LCL 1	Deviation From Mean	Cusum Value	UCL 2	LCL 2
1	31.80	32.17	32.55	31.87	-2.10	-2.10	1.79	-5.16
2	32.15	32.24	32.64	31.78	0.29	-1.82	1.72	-5.10
3	32.16	32.22	32.69	31.73	-0.04	-1.86	1.65	-5.03
4	31.88	31.99	32.72	31.70	-1.16	-3.02	1.59	-4.96
5	31.95	32.04	32.74	31.68	0.03	-2.99	1.52	-4.89
6	32.26	32.40	32.75	31.67	1.62	-1.37	1.45	-4.83
7	32.13	32.18	32.76	31.66	-0.91	-2.29	1.38	-4.76
8	32.27	32.40	32.77	31.66	1.06	-1.23	1.32	-4.69
9	32.23	32.31	32.77	31.65	-0.25	-1.48	1.25	-4.62
10	32.24	32.31	32.77	31.65	0.13	-1.36	1.18	-4.56
11	32.22	32.25	32.77	31.65	-0.21	-1.57	1.11	-4.49
12	32.29	32.42	32.77	31.65	0.87	-0.70	1.05	-4.42
13	32.23	32.22	32.77	31.65	-0.78	-1.48	0.98	-4.35
14	32.21	32.16	32.77	31.65	-0.27	-1.75	0.91	-4.29
15	32.15	32.00	32.77	31.65	-0.87	-2.62	0.84	-4.22
16	32.09	31.84	32.77	31.65	-1.02	-3.64	0.78	-4.15
17	32.09	31.88	32.77	31.65	-0.18	-3.82	0.71	-4.08
18	32.09	31.93	32.77	31.65	-0.07	-3.89	0.64	-4.02
19	32.07	31.90	32.77	31.65	-0.44	-4.34	0.57	-3.95
20	32.09	32.00	32.77	31.65	0.18	-4.15	0.51	-3.88
21	32.09	32.04	32.77	31.65	-0.01	-4.16	0.44	-3.81
22	32.09	32.05	32.77	31.65	-0.12	-4.29	0.37	-3.75
23	32.11	32.14	32.77	31.65	0.28	-4.01	0.30	-3.68
24	32.25	32.79	32.77	31.65	3.18	-0.83	0.24	-3.61
25	32.23	32.59	32.77	31.65	-0.42	-1.25	0.17	-3.55
26	32.21	32.41	32.77	31.65	-0.50	-1.76	0.10	-3.48
27	32.20	32.33	32.77	31.65	-0.22	-1.98	0.03	-3.41
28	32.21	32.36	32.77	31.65	0.26	-1.72	-0.03	-3.34
29	32.22	32.38	32.77	31.65	0.25	-1.47	-0.10	-3.28
30	32.21	32.30	32.77	31.65	-0.22	-1.69	-0.17	-3.21

An Exponentially Weighted Moving Average chart is constructed for CASE 1 with the above-calculated values and an analysis is presented for the same.

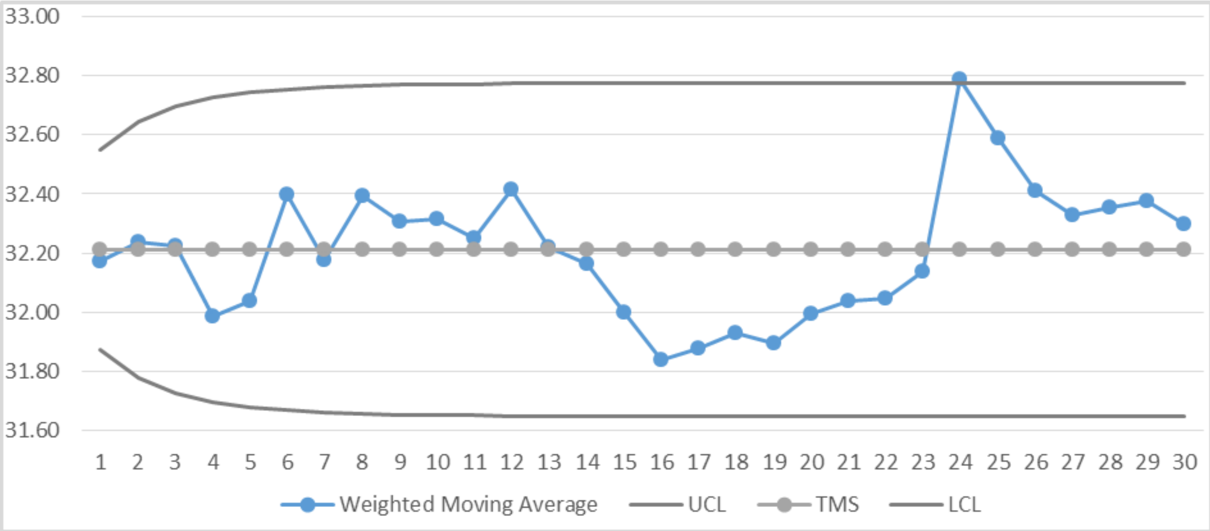

Figure 2: EWMA chart for M25grade of concrete of 28-day compressive strength

For the analysis of Fig-2, Sample 24 moves outside the control limits when the limits are set to the 3-Sigma. Although it rises progressively, it moves all out of the control limit all of a sudden which shows a random or a special cause variation. All the previous sample points are below the centerline and therefore it shows a variation of 3 times the standard error (3σ variation). A Root-Cause-Analysis is mandatorily suggested for this sample. As removing random or special cause is the primary need for any control charts in statistical quality control. In addition, all these points are on the same side of the centerline, which is also not a good sign for a production unit. Samples 14 to 23 i.e. continuously 10 samples are on one side of the centerline. It shows that the concrete strength is continuously observing the same strength-gaining trend and still no action has been taken. Also if the 24th sample would not have been lifting the whole smoothened value above, then still many values would be below the centerline. This shows that the smoothened values are able to detect the small shifts, as early as 12th sample. There are many small continuous trends in the chart i.e from sample 6 to 13 except sample 7 all are on the higher side of centerline and then from sample 14 to sample 23 all the sample points lie below the centerline. Therefore, it can be said that the chart does not observe a random trend. This shows the negligence of the operators as the random scattering is not observed. The point of action should be at sample 9 or 10 for the initial half and then at sample 16 or 17 for the latter half. Atleast some minor modification should have been done so as to have an economic mix with desired strength.

When the same case i.e. CASE 1 is analyzed with V-mask cusum technique chart with the values as calculated in Table 2, the results obtained are

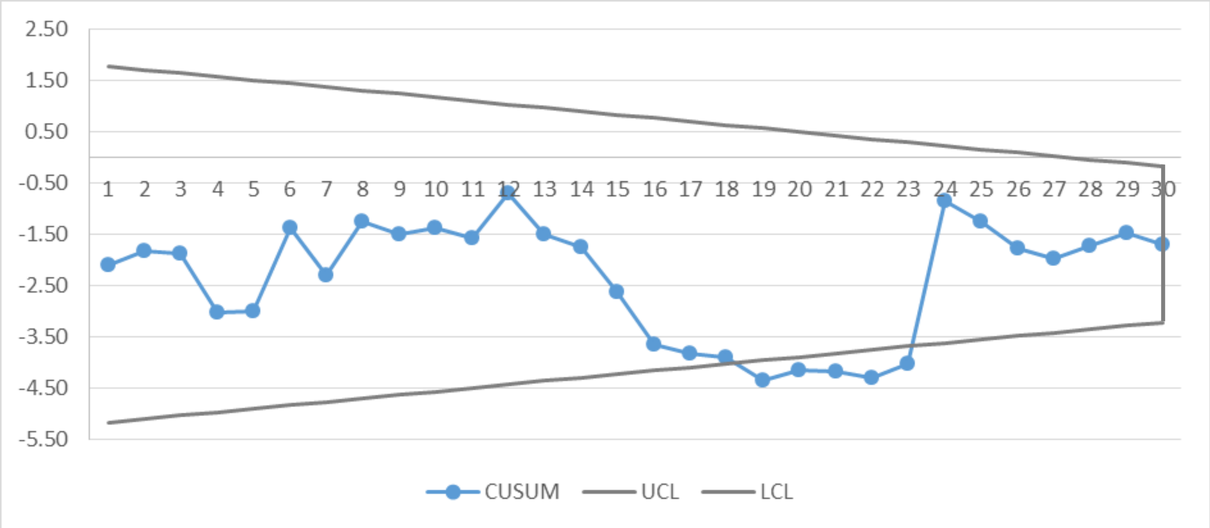

Figure 3: CUSUM with V-mask chart for M25grade of concrete of 28-day compressive strength

From sample 9 till sample 14 except sample 12 shows a linear kind of graph; in CUSUM chart previous values are added so it can be said that these samples show nearly zero variation. Sample 17 moves out of the control limits strength chart and it is the 5th consecutive point in the downward trend. So, corrective action could have been triggered at sample number 15 or 16 itself. Here sample 19 is out of the control limit with previous 6 points showing downward trend. This should have been adequate signaling to trigger the reaction plan, but no corrective action is being taken. A sudden increase in CUSUM value at sample 24 shows a sudden increase as compared to sample 23 in the strength of concrete randomly with an increase of 3,66 units(more than 3-sigma; relatively).

Similar calculations are made for case 2 and the analysis is presented below.

With the EWMA control chart the analysis id as follows:

First 10 samples are outside the upper control limits. This shows over conservative design. Sample 19 needs a root-cause analysis because a continuous declination of 11 samples has taken place and still if the sample goes beyond the lower control limit, it is totally unacceptable. The control action should have been triggered itself at sample 15 Sample 9 to 19 show a downward trend of 11 samples. Sample 20 to 24 show a upward trend. Samples 25 to 30 i.e. 6 samples are continuously in the 1-sigma limit. There is a continuous curve forming 2 ridges and a valley within consisting of 16 samples which is not a good sign. It shows complete negligence and there may not be any recovery action taking place.

With the V-mask cusum control chart the analysis id as follows:

With sample number 5 going outside the defined limits till the sample number 17, the control action should have been triggered from sample number 4 itself. As experts suggest, the upward trend has started from the first sample itself but the sample nearest but one to the control limits is sample number 3, so to make the production safer, the control action has to be triggered at sample number 3. Until sample 9 the chart show a continuous increase that shows that there is a stipulated unadjusted factor of safety. The chart then from sample 9 to sample 23 shown continuous downward trend so it can be concluded that either the machine or workmanship is poor.

The highest CUSUM value is 11.56 of sample 9, this shows that there is an unmonitored production as the chart should show some kind of randomness, but the chart shows a continuous increase and then continuous decrease in the strength values. With a total of 12 samples out of 30 samples going outside the control limits, it shows that nearly 1/3rd of the produced concrete is having a higher variation from the nominal allowed variation.

V. CONCLUSION

With nearly only 25% samples showing random behavior when compared in both the charts, one can say that even when the plant standard deviation is as low as 0.961 the concrete quality is not that reliable.

It can also be interpreted that V-mask cusum chart is a bit easy to construct but difficult to interpret, as the point of action is not the point moving out of the control limits. This is because we do not put down the original values directly but we highly modify the original values and all the previous statistically modified values are taken into consideration.

It can also be said that EWMA charts are relatively difficult to construct as the decision for the value of L and Lambda (λ) is to be taken. And these constants change with each industry. But, ones the decision is taken based on the adequate numbers of sample then these charts are easy to interpret. The reason being that, we only smoothen the original reading slightly and then the control limits are modified and not the sample data.

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