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Original Research Article

Evaluation of sigma metrics in a Medical Biochemistry lab

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Abstract

Sigma metrics is calculated in our lab and evaluated from December 2013 to November 2014. It is observed that Triglycerides, Lactate, Uric acid, AST, Urea, Creatine kinase(CK), Phosphate, Total Bilirubin are the best performers and the sigma value is more than 6.0 in both in normal and abnormal levels. Iron and Creatinine are best performers in normal level and Prolactin and Vitamin B12 are best performers in abnormal level. Amylase and LDH are the poor performers at level 1 (normal), though they show sigma between 3 to 6 at level 2 which is clinically acceptable.

Keywords: Six sigma, Sigma metrics, Percentage Bias, Total allowable error, Total analytical error, Coefficient of variance

1.Introduction

It is the time to improve the quality accompanied by reduction of cost in healthcare system of both public and private sectors. This pressurises to implement Total Quality Management which includes Quality planning, Quality Laboratory Process, Quality Control, Quality assessment, Quality Improvement. Quality refers to satisfaction of the needs and expectations of the users or customers. Fundamental requirements for all objective quality control systems are clearly defined quality goals. Laboratories must define their service goals and establish clinical analytical requirements for testing processes. Without such quality goals, there is no objective way to determine whether acceptable quality is being achieved.

Six sigma is an evolution in quality management that is being widely implemented in business and industry in the new millennium. The principles of Six sigma was adopted by Motorola in early 1990s and won the award of Malcolm Baldridge Quality Award. The application of sigma metrics for assessing analytical performance depends on measuring the process variation and determining process capability in sigma units. Sigma(σ) is the mathematical symbol for standard deviation(SD).

Any process can be evaluated in terms of a sigma metric that describes how many sigma's fit within the tolerance limits. Two methods can be used to assess the process performance in terms of a sigma metric. One approach is to measure outcomes by inspection. The other approach is to measure variation and predict process performance. Measurement of outcome is done by calculating defects per million(DPM) and converting it into sigma metric. A defect rate of 0.033% would be considered excellent in any healthcare organization, where error rates from 1 to 5% are often considered acceptable. A 5% error rate corresponds to a 3.15 sigma performance, and a 1% error rate corresponds to 3.85 sigma. Quality is assessed on the sigma scale with a criterion of 3 σ as the minimum allowable sigma for routine performance and a sigma of 6 σ being the goal for world-class quality.[1] To achieve Six sigma goal, the error rate should be 0.1% (4.6

sigma) to 0.01% (5.2 sigma) and ultimately 0.001% (5.8 sigma).[2] We aimed to gauze the sigma values on sigma metrics scale.

2. Materials and Methods

Six Sigma is unique in its rigorous approach to outlining the details that are necessary to achieve significant improvement in process quality and efficiency. The process begins with developing a clear understanding of required performance. It then applies a variety of statistical tools to analyze process measures, which facilitates proving the root cause(s) for problem(s). The task then becomes revising the process in order to eliminate the causative factor(s).

We determined the sigma values for various parameters and evaluated sigma metrics from December 2013 to November 2014. Sigma (σ) value is calculated with the formula Sigma metrics (σ) = (TEa % - Bias %**)** / CV% where TEa% is Total allowable error percentage and CV% is Coefficient of Variation.

2.1 Precision

Precision has been defined as the closeness of agreement between independent results of measurements obtained under stipulated conditions. The degree of precision is usually expressed on the basis of statistical measures of imprecision, such as ***CV%***. CV% is calculated from Internal Quality Control (IQC) data with the formula CV% = (SD/Mean)* 100. Monthly CV% of all the analytes from Dec 2013 to Nov 2014 is shown in Table 1 and Table 2.

2.2 Trueness

Trueness is defined as closeness of agreement between the average value obtained from a large series of results of measurements and the true value. The difference between the average value and the true value is the ***bias***, which is expressed numerically and so is inversely related to the trueness. Bias% is calculated from External Quality Assurance Scheme (EQAS) with the formula:

Bias% = [(Our lab result - Peer group mean) / (Peer group mean)]*100. Bias% of all the analytes from Dec 2013 to Nov 2014 is shown in Table 3.

Various parameters observed are Amylase, ALT, ALKP, AST, Conjugated Bilirubin, Total Bilirubin, Cholesterol, Creatine kinase, Creatinine, Glucose, HDL Cholesterol, Iron, Lactate, LDH, iPTH, Phosphorus, Potassium, Prolactin, PSA, Triglycerides, Uric acid, Urea, Vitamin B12 . The analysers used are Vitros 5.1FS, Rochester, U.S.A. and Advia Centaur CP, Marburg, Germany. Internal and External Controls are procured from Biorad Laboratories, Irvine, U.S.A. Internal controls are of lyophilsed serum materials of different concentrations one being the physiological/normal level (Level 1) and the other of pathological level/abnormal (Level 2).

In our sudy, Total allowable errors (TEa) for calculating the sigma metrics are taken from the guidelines of Dr. Carmen Ricos and her colleagues.[3] TEa for various parameters is as follows: Amylase-17.5, ALT-32.4, ALKP-13.9, AST-19.2, Conjugated Bilirubin-57.1, Total Bilirubin-39.1, Cholesterol-10.3, Creatine kinase-38.1, Creatinine-11.0, Glucose-9.3, HDL Cholesterol-13.5, Iron-39.7, Lactate-39.7, LDH-14.3, iPTH-39.0, Phosphorus-13.1, Potassium-7.4, Prolactin-37.3, PSA-39.7, Triglycerides-35.0, Uric acid-15.4, Urea-19.8, Vitamin B12-35.1.[3]

3. Results

Among the 23 analytes observed in Level 1 (normal level) Triglycerides, Lactate, Uricacid, Iron, AST, Urea, Creatine kinase, Phosphorus, Prolactin, Total Bilirubin, Creatinine showed the performance of more than 6 sigma. Cholesterol, Vitamin B12, Glucose, iPTH, ALKP, Potassium, PSA, Conjugated Bilirubin, ALT, and HDL Cholesterol showed 3 – 6 sigma performance. LDH and Amylase are poor performers (sigma metrics is less than 3.0) (Table 4) (Figure 1)

In level 2 (pathological level) Triglycerides, Lactate, Total Bilirubin, ALT, AST, Urea, Uricacid, Creatine kinase, Phosphorus, Cholesterol, Vitamin B12 showed the performance of more than 6 sigma. Prolactin, LDH, ALKP, Amylase, Creatinine, Glucose, PSA, iPTH, Conjugated Bilirubin, Iron, HDL Cholesterol, and Potassium showed the performance between 3 and 6. (Table 5) (Figure 2)

4. Discussion

In a routine accredited clinical biochemistry laboratory it is conventional practice to run the Internal and External quality controls to assess precision and accuracy. In this practice, laboratory personnel usually follow the Westgard rules like 12S, 13S, R4S, and 10X for internal quality assurance.

Rule 12S indicates one control observation exceeding the mean ± 2 standard deviations is used as a warning rule that intiates testing of the control data by the other control rules.

Rule 13S indicates one control observation exceeding the mean ± 3 standard deviations is rejection rule that is primarily sensitive to a random error,

Rule 22S indicates two control observations exceeding the same mean plus 2 standard deviations or minus 2 standard deviations limit is rejection rule that is sensitive to systematic error.

Rule R4S indicates one observation exceeding the mean plus 2 standard deviation and the other exceeding the mean minus 2 standard deviation is a rejection rule that is sensitive to random error.

Rule 10 x indicates ten consecutive control observations falling one side of the mean is a rejection rule that is sensitive to systematic error.[2]

Common checklist followed when a systemic error is noted includes:

1. Change in the Reagent/Control/ numbers.
1. Weekly / monthly maintenance due.
2. Date and Time of current calibration.
3. Calibrator lot change.
4. Any maintenance / Service done since the shift /trend is noted.
5. Any lamp change / lamp deterioration.
6. Reagent shelf / on board stability.
7. Date of reconstitution of the control.
8. Status after repetition of control.
9. Correlation of lab Mean and SD with peer group Mean and SD.

Common checklist for corrective action when a random error is noted includes:

1. Proper mixing of the control.
2. Any bubbles noted in aliquot.
3. Shelf life of reconstituted control.
4. Temperature/humidity of environment and instrument.
5. Calibration status.
6. Electricity fluctuation.
7. Reagent/control/calibrator lot change.
8. Any instrument error.
9. Status after repetition of the control.

In External Quality Assurance Services (EQAS) when ' Z ' score (or) Standard Deviation Index (SDI) is between +2 and -2, it is considered as accuracy is satisfactory. If Z-score is out of this range it indicates the process is biased.When the process is biased the frequent corrective actions include calibrating the parmeter, Reagent change, Maintenance of intrument, EQAS sample handling, technician change, sending the sample for Inter Laboratoty Comparison, EQAS evaluation.

Internal Quality Control (IQC) programme can proffer CV% which represents laboratory precision and EQAS can provide Bias% representing the accuracy.

Total error (TE) = 1.96 * CV% + Bias %. CV% can be calculated from the internal quality control and Bias percentages can be known from EQAS results. So, it is clear that calculation of total error takes into the consideration of both precision and accuracy. From this it appears that if Total error (TE) is less than Total allowable error (TEa), we can cosider the process satisfactory. But it is not so because other factors like sample carry over, non linear bias and sample matrix effects can also affect the Total analytical error.[4] Total analytical error (TE) for observed analytes from Dec 2013 to Nov 2014 is showed in Table 6 and Table 7.

Total allowable errors (TEa) for different analytes are published by different groups like Clinical Laboratory Improvement Amendments (CLIA), Royal College of Australasian Pathologists (RCPA), as well as the Guidelines of the German Medical Association (RiliBäk). Dr. Carmen Ricos and her colleagues have provided a continuously updated database of biologic variation since 2000. For over 300 different analytes, they have tabulated desirable specifications for imprecision, inaccuracy, and total allowable error.[5]

The Six Sigma scale typically runs from zero to six, but a process can actually exceed Six Sigma, if variability is sufficiently low as to decrease the defect rate. In industries outside of healthcare, 3 Sigma is considered the minimal acceptable performance for a process. When performance falls below 3 Sigma, the process is considered to be essentially unstable and unacceptable.[5]

In contrast to other industries, healthcare and clinical laboratories appear to be operating in a 2 to 3 Sigma environment. The routine use of "2s" (i.e., 2 standard deviations or 2 SD) control limits is indicative of a complacent tradition in quality control practices. Despite the well-known problems of 2s limits – they can generate false rejection rates of up to 10 to 20%, depending on the number of controls run– many laboratories use them for all testing processes. The misuse of 2s limits in laboratory testing frequently results in erroneously-repeated controls, excessive trouble-shooting, or worse still, workarounds that artificially widen control limits to the point that laboratories can no longer detect critical analytical errors.

Six sigma scale has the power to provide a universal bench mark. It allows the comparison between different instruments, different labs and different methods all over the world. Nevalainen's data on Sigma assessment in preanalytic, analytic and post analytic phases of the clinical lab showed that many were not adequate.[6] Nanda *et al* data showed that out of the 13 analytes evaluated for sigma assessment in their laboratory, 5 analytes showed the

performance of above 6 sigma, 4 analytes showed the performance between 3 to 6 sigma metrics and remaining 4 showed the performance of below 3 sigma metrics.[7] Singh *et al* data showed that among the 15 analytes observed for sigma assessment three analytes showed the performance of below 3 sigma metrics.[8]

In present study, 11 of 23 analytes showed above six sigma performances, 10 analytes showed 3 to 6 sigma performance, 2 analytes showed less than 3 sigma performances in normal level (level 1). Sigma metrics of abnormal level (level 2) showed 11 of 23 analytes showed above six sigma performances, 12 analytes showed the performance between 3 and 6.

Though many laboratories are following the ISO 15189 guidelines and participating in the Internal and external quality control programmes, unable to achieve the six sigma performance. Six sigma being the goal for world-class quality, there is a need to implement the sigma metrics in the laboratories. Sigma metrics in combination with a rational QC design for each analyte can improve the quality there by reducing the wastage. [5]

Schoenmaker *et al* described the importance of application of sigma metrics and preparation of rational QC design based on the sigma values with the help of westgard operational specifications chart (OPSpecs chart) in clinical biochemistry laboratories.[9] An example of QC design is shown in the Table 8.

Table 1: Coefficient of Variance (CV %) Level 1 Monthly wise Dec 2013 – Nov 2014

Analyte	Dec 2013	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	AVG CV%
Amylase	6.5	5.72	3.36	5.22	5.66	5.09	5.09	6	7.9	5.12	6.44	3.87	5.4
ALT	7.89	8.15	6.52	8	8.09	9.53	9.53	10.43	11.18	7.42	6.2	10.37	8.6
ALKP	1.89	1.85	2.24	3.5	2.8	2.02	2.02	2.1	2.65	4.38	2.2	2.16	2.4
AST	2.26	2.03	2.13	2.63	1.94	1.65	1.65	1.44	1.86	1.3	1.81	1.78	1.8
Conjugated bilirubin	12.5	8.6	9.9	12.7	10.5	13	13	8.5	8	14.9	13.1	7.7	11.0
Total Bilirubin	2.97	4.98	3.58	4.18	5.61	5.05	5.05	5.27	5.32	5.81	6.55	4.6	4.9
Cholesterol	0.89	1.74	0.93	1.89	1.14	1.59	1.59	1.94	1.73	1.65	1.01	1.5	1.4
CreatineKinase (CK)	4.7	7.43	4.94	5.24	3.57	3.33	3.33	5.49	4.78	3.19	3.02	3.45	4.3
Creatinine	1.52	1.76	1.43	2.37	1.46	1.24	1.24	0.99	1.31	1.09	1.07	1.4	1.4
Glucose	1.02	1.32	0.99	3.56	1.06	0.99	1.26	1.19	2.46	1.74	1.07	0.99	1.4
HDL Cholesterol	2.8	1.88	2.26	3.3	2.99	3.63	4.72	3.19	4.22	3.3	3.49	4.08	3.3
Iron	3.86	3.29	3.65	4.07	2.89	2.29	2.35	2.95	4.52	4.51	4.42	4.11	3.5
Lactate	0.97	1.44	1.79	3.09	3.01	1.56	1.61	0.93	0.71	1	1.32	0.94	1.5
LDH	4.83	4.21	4.02	6.15	5.13	4.83	3.63	4.88	3.44	3.73	4.18	4.17	4.4
iPTH	5.1	10.29	6.26	4.63	7.83	8.79	2.84	6.96	5.84	7.18	13.38	12.03	7.5
Phosphate	0.96	2.7	0.61	1.24	1.01	1.41	1.29	0.99	1.76	2.77	0.74	1.04	1.3
Potassium	0.96	1.73	1.15	0.94	0.62	0.84	5.99	0.52	1.67	2.92	1.3	1.51	1.6
Prolactin	1.12	5.03	6.19	9.18	9.04	7.06	8.32	5.2	3.9	1.62	7.57	4.09	5.6
PSA	9.04	3.69	7.92	6.78	4.21	6.67	2.14	11.68	7.92	11.89	13.89	11.4	8.1
Triglycerides	1.06	1.65	0.93	1.09	1.09	1.07	0.92	0.89	1.69	1.24	1.46	0.84	1.1
Uric acid	0.86	1	0.92	2.54	1.15	1.09	1.34	1.53	1.09	1.17	1.13	0.92	1.2
Urea	1.91	2.25	1.35	2.41	1.8	1.71	1.97	1.55	1.61	2.02	1.48	1.9	1.8
Vitamin B12	5.07	5.17	5.36	12.63	8.23	9.4	6.69	2.67	7.84	2.5	5.14	7.07	6.4

Table 2: Coefficient of Variance (CV %) Level 2 Monthly wise Dec 2013 – Nov 2014

Analyte	Dec 2013	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	AVG CV%
Amylase	2.28	3.85	1.31	1.84	2.19	3.08	2.67	1.8	2.21	3	4.27	1.8	2.5
ALT	2.53	2.52	3.12	3.44	2.34	1.73	2.96	3.31	2.68	2.79	1.91	2.07	2.6
ALKP	2.09	2.03	1.68	3.12	1.35	1.94	1.87	1.59	1.81	2.79	1.95	2.14	2.0
AST	1.72	1.65	2.27	2.27	1.7	1.7	1.05	1.77	1.32	1.37	1.34	1.66	1.6
Conjugated bilirubin	6.93	7.5	5.95	7.58	6.2	7.98	8.01	12.62	8.95	7.46	11.45	8.39	8.2
Total Bilirubin	1.25	3.06	2.33	2.48	1.91	2.13	1.76	2.15	2.69	4.26	1.54	1.26	2.2
Cholesterol	0.96	3.2	1.05	0.95	0.97	0.96	1.38	1.37	1.43	1.86	0.74	0.85	1.3
Creatine kinase (CK)	7	7.95	6.22	9.88	3.18	3.13	3.78	2.47	3.02	2.22	2.64	2.59	4.5
Creatinine	1.32	1.97	2.24	2.05	2.01	1.64	1.75	2.41	1.18	1.66	1.43	1.32	1.7
Glucose	1.05	1.95	1.36	1.48	1.09	1.33	1.21	1.32	1.79	2.12	1.49	0.94	1.4
HDL Cholesterol	2.83	1.32	1.74	2.61	2.19	2.69	2.54	1.56	2.87	3.05	2.58	2.02	2.3
Iron	6.62	4.45	8.54	6.95	6.66	5.6	8.95	10.46	9.77	7.2	10.75	11.44	8.1
Lactate	2.25	2.64	2.39	3.94	2.61	1.6	2.06	1.68	1.91	2.02	1.54	2.73	2.2
LDH	2.84	1.57	2.09	1.77	1.74	1.62	1.66	1.73	1.87	1.4	1.59	1.37	1.7
iPTH	11.7	2.27	3.78	7.96	9.56	9.97	12.8	7.54	13.08	6.45	8.02	3.14	8.0
Phosphate	1.45	2.21	0.86	1.67	0.83	1.24	2.04	0.92	1.02	2	0.74	0.91	1.3
Potassium	0.88	3.45	1.25	0.86	1.09	1.18	0.87	0.62	1.98	2.94	1.03	1.4	1.4
Prolactin	7.14	1.63	8.92	5.46	3.56	8.51	6.67	3.18	4	4.67	5.99	8.44	5.6
PSA	8.59	1.42	8.52	8.69	8.82	5.79	11.5	10.25	11.14	9.87	11.53	7.36	8.6
Triglycerides	1.1	3.54	0.78	1.02	2.56	1.24	1.26	1.46	1.67	2.17	1.08	1.3	1.5
Uric acid	1.13	1.72	1.23	2.53	2.2	1.55	1.15	1.26	0.99	1.59	1.26	0.98	1.4
Urea	1.33	1.82	1.67	1.75	1.19	1.25	1.27	2.24	2.06	2.08	1.67	1.52	1.6
Vitamin B12	4.19	4.17	5.37	5.41	1.44	7.01	6.82	5.65	6.18	7.52	5.71	5.77	5.4

Table 3: BIAS % Monthly wise Dec 2013 – Nov 2014

Analyte	Dec 2013	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	AVG Bias%
Amylase	6.13	12.5	0.3	0.7	16.1	7.28	4.24	3.46	6.29	6.38	0.95	9.06	6.1
ALT	24.6	1.72	1.94	13.5	3.03	2.46	6.78	7.22	6.24	0.71	6.06	0.668	6.2
ALKP	0.133	5.54	7.82	1.17	1.12	6.72	3.28	2.19	2.78	0.3	2.38	1.46	2.9
AST	2.69	1.55	1.91	0.57	0.782	0.3	1.36	2.33	4.83	5.63	2.77	5.96	2.5
Conjugated bilirubin	17.2	15.3	25.7	8.01	0.268	36.5	47.2	16.8	0.43	41.3	23.7	11.9	20.3
Total Bilirubin	1.41	0.19	1.07	6.11	12.7	8.42	5.56	5.67	7.23	0.45	11.4	22.5	6.8
Cholesterol	1.98	2.09	1.12	5.92	0.519	1.86	0.86	2.81	0.98	2.42	3.74	3.51	2.3
Creatine kinase (CK)	0.165	0.1	3.42	4.26	0.918	1.85	6.53	0.44	6.55	0.98	4.7	2.26	2.6
Creatinine	0.173	2.54	2.58	1.72	5.15	2.57	0.5	1.11	1.49	2.81	3.73	4.39	2.3
Glucose	6.55	1.58	0.339	0.35	0.257	1.74	3.78	0.912	2.89	2.88	2.31	6.44	2.5
HDL Cholesterol	5.31	2.53	4.32	7.18	5.95	1.08	1.97	0.603	4.87	7.41	2.08	3.97	3.9
Iron	5.04	2.99	2.13	6.04	13	1.66	7.52	6.84	4.13	6.2	2.06	14.3	5.9
Lactate	0.702	3.1	1.01	8.68	0.472	0.136	0.55	0.48	3.67	4.79	1.63	3.13	2.3
LDH	5.74	3.67	1.39	7.18	2.27	7.86	5.11	3.73	2.32	4.5	1.72	4.1	4.1
iPTH	5.33		10.3	3.42	2.71	5.47	0.24	1.09	0.3	3.96	10.9	3.2	3.9
Phosphate	2.7	12.7	3.16	4.23	7.83	0.3	4.05	0.965	0.753	0.56	4.25	2.69	3.6
Potassium	1.29	11.2	6.8	2.37	7.75	4.05	0.098	0.235	0.23	2.13	1.09	0.189	3.1
Prolactin	16.3	3.37	1.19	0.83	7.65	0.723	0.8	13.5	13.8	5.29	4.99	2.44	5.9
PSA	9.79	10.5	17.1	10.5	7.11	0.32	0.23	18.8	7.39	1.83	5.48	7.9	8.0
Triglycerides	0.06	8.13	0.5	2.19	1.28	2.47	0.22	0.428	4.1	1.67	0.19	8.05	2.4
Uric acid	2.45	0.58	1.96	0.14	0.293	0.478	1.05	1.98	0.77	0.27	1.71	5.04	1.3
Urea	4.32	6.23	1.09	2.59	5.19	2.59	2.34	2.23	2.86	0.17	11.9	0.667	3.5
Vitamin B12	0.618	1.52	8.15	3.97	2.45	19.5	1.83	4.57	6.09	1.82	5.95	1.77	4.8

Table 4: Sigma Metrics Level 1 (Monthly wise Dec 2013 – Nov 2014)

Analyte	Dec 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	AVG Sigma
Triglycerides	33	16.3	37.1	30.1	30.9	30.4	37.8	38.8	18.3	26.9	23.8	32.1	29.6
Lactate	40.2	25.4	21.6	10	13	25.4	24.3	42.2	50.7	34.9	28.8	38.9	29.6
Uric acid	15.1	14.8	14.6	6	13.1	13.7	10.7	8.8	13.4	12.9	12.1	11.3	12.2
Iron	9	11.2	10.3	8.3	9.2	16.6	13.7	11.1	7.9	7.4	8.5	6.2	9.9
AST	7.3	8.7	8.1	7.1	9.5	11.5	10.8	11.7	7.7	10.4	9.1	7.4	9.1
Urea	8.1	6	13.9	7.1	8.1	10.1	8.9	11.3	10.5	9.7	5.3	10.1	9.0
Creatinekinase(CK)	8.1	5.1	7	6.5	10.4	10.9	9.5	6.9	6.6	11.6	11.1	10.4	8.6
Phosphate	10.8	0.1	16.3	7.2	5.2	9.1	2.6	12.3	7	4.5	12	10	8.0
Prolactin	18.8	6.7	5.8	4	3.3	5.2	4.7	4.6	6	19.8	4.3	8.5	7.6
Total Bilirubin	12.7	7.8	10.6	7.9	4.7	6.1	6.6	6.3	6	6.7	4.2	3.6	6.9
Creatinine	7.1	4.8	5.9	3.9	4	6.8	8.5	10	7.3	7.5	6.8	4.7	6.4
Cholesterol	9.3	4.7	9.9	2.3	8.6	5.3	5.9	3.9	5.4	4.8	6.5	4.5	5.9
Vitamin B12	6.8	6.5	5	2.5	4	1.7	5	11.4	3.7	13.3	5.7	4.7	5.8
Glucose	2.7	5.8	6.8	2.5	8.5	7.6	4.4	7	2.6	3.7	6.5	2.9	5.0
iPTH	6.6	3.8	4.6	7.7	4.6	3.8	4.5	5.4	6.6	4.9	2.1	3	4.8
ALKP	7.3	4.5	2.7	3.6	4.6	3.6	5.3	5.6	4.2	3.1	5.2	5.8	4.6
Potassium	6.4	-2.2	0.5	5.4	-0.6	4	6.2	13.8	4.3	1.8	4.9	4.8	4.1
PSA	3.3	7.9	2.9	4.3	7.7	5.9	1.9	1.8	4.1	3.2	2.5	2.8	4.0
Conjugated bilirubin	3.2	4.9	3.2	3.9	5.4	1.6	0.8	4.7	7.1	1.1	2.5	5.9	3.6
ALT	1	3.8	4.7	2.4	3.6	3.1	2.7	2.4	2.3	4.3	4.2	3.1	3.1
HDL Cholesterol	2.9	5.8	4.1	1.9	2.5	3.4	2.4	4	2	1.8	3.3	2.3	3.0
LDH	1.8	2.5	3.2	1.2	2.3	1.3	2.5	2.2	3.5	2.6	3	2.4	2.3
Amylase	1.7	0.9	5.1	3.2	0.2	2	2.6	2.3	1.4	2.2	2.6	2.2	2.2

Figure1: Graph showing Sigma Metrics Level - 1 (Dec 2013 to Nov 2014)

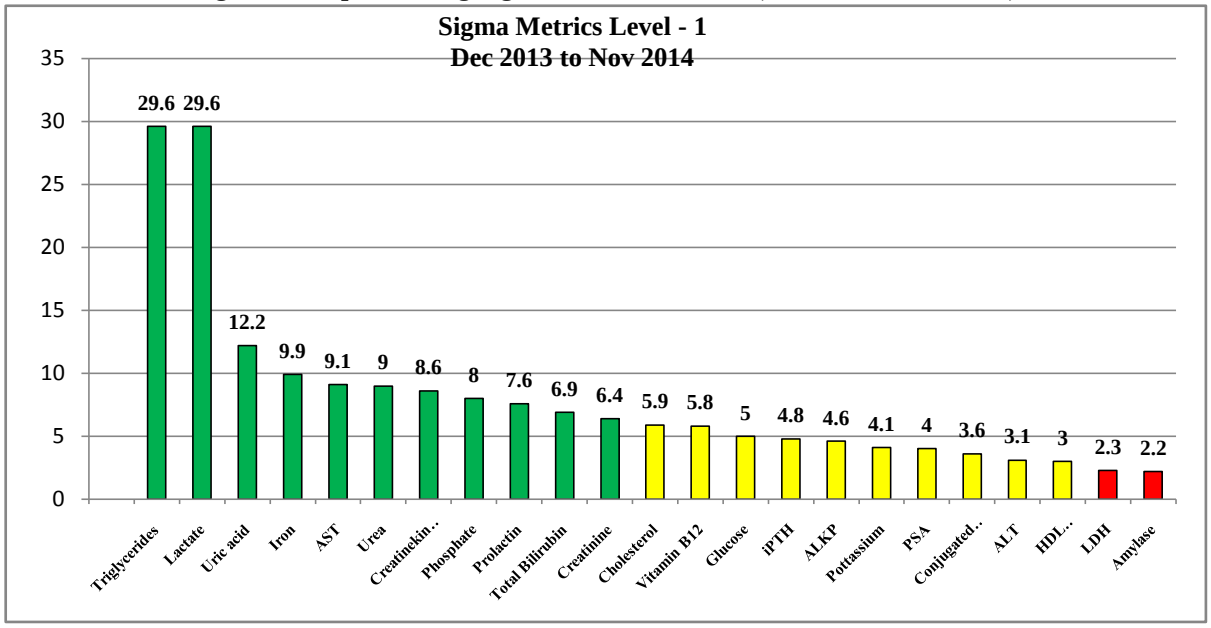

Table 5: Sigma Metrics Level – 2 (Monthly wise Dec 2013 – Nov 2014)

Analyte	Dec 2013	Jan 2014	Feb 2014	Mar 2014	Apr 2014	May 2014	Jun 2014	Jul 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014	AVG Sigma
Triglycerides	31.8	7.6	44.2	32.2	13.2	26.2	27.6	23.7	18.5	15.4	32.2	20.7	24.4
Lactate	17.3	13.9	16.2	7.9	15	24.7	19	23.3	18.9	17.3	24.7	13.4	17.6
Total Bilirubin	30.2	12.7	16.3	13.3	13.8	14.4	19.1	15.5	11.8	9.1	18	13.2	15.6
ALT	3.1	12.2	9.8	5.5	12.6	17.3	8.7	7.6	9.8	11.4	13.8	15.3	10.5
AST	9.6	10.7	7.6	8.2	10.8	11.1	17	9.5	10.9	9.9	12.3	8	10.4
Urea	11.6	7.5	11.2	9.8	12.3	13.8	13.7	7.8	8.2	9.4	4.7	12.6	10.2
Uric acid	11.5	8.6	10.9	6	6.9	9.6	12.5	10.7	14.8	9.5	10.9	10.6	10.2
Creatine kinase(CK)	5.4	4.8	5.6	3.4	11.7	11.6	8.4	15.2	10.4	16.7	12.7	13.8	9.9
Phosphate	7.2	0.2	11.6	5.3	6.3	10.3	4.4	13.2	12.1	6.3	12	11.4	8.3
Cholesterol	8.7	2.6	8.7	4.6	10.1	8.8	6.8	5.5	6.5	4.2	8.9	8	6.9
Vitamin B12	8.2	8.1	5	5.8	22.7	2.2	4.9	5.4	4.7	4.4	5.1	5.8	6.8
Prolactin	2.9	9.8	4	6.7	8.3	4.3	5.5	7.5	5.9	6.9	5.4	4.1	5.9
LDH	3	6.8	6.2	4	6.9	4	5.5	6.1	6.4	7	7.9	7.4	5.9
ALKP	6.6	4.1	3.6	4.1	9.5	3.7	5.7	7.4	6.1	4.9	5.9	5.8	5.6
Amylase	5	1.3	13.1	9.1	0.6	3.3	5	7.8	5.1	3.7	3.9	4.7	5.2
Creatinine	8.2	4.3	3.8	4.5	2.9	5.1	6	4.1	8.1	4.9	5.1	5	5.1
Glucose	2.6	4	5	6	8.3	5.7	6.2	6.4	3.6	3	4.7	3	4.8
PSA	3.5	17.9	2.7	3.4	3.7	6.8	3.4	2	2.9	3.8	3	4.3	4.7
iPTH	2.9	3.8	7.6	4.5	3.8	3.4	3	5	3	5.4	3.5	11.4	4.7
Conjugated Billirubin	5.8	5.6	5.3	6.5	9.2	2.6	1.2	3.2	6.3	2.1	2.9	5.4	4.6
Iron	5.2	8.2	4.4	4.8	4	6.8	3.6	3.1	3.6	4.7	3.5	2.2	4.5
HDL Cholesterol	2.9	8.3	5.3	2.4	3.4	4.6	4.5	8.3	3	2	4.4	4.7	4.4
Potassium	6.9	-1.7	0.5	5.8	-0.3	2.8	8.4	11.6	3.6	1.8	6.1	5.2	4.2

Figure 2: Graph showing Sigma Metrics Level - 2 (Dec 2013 to Nov 2014)

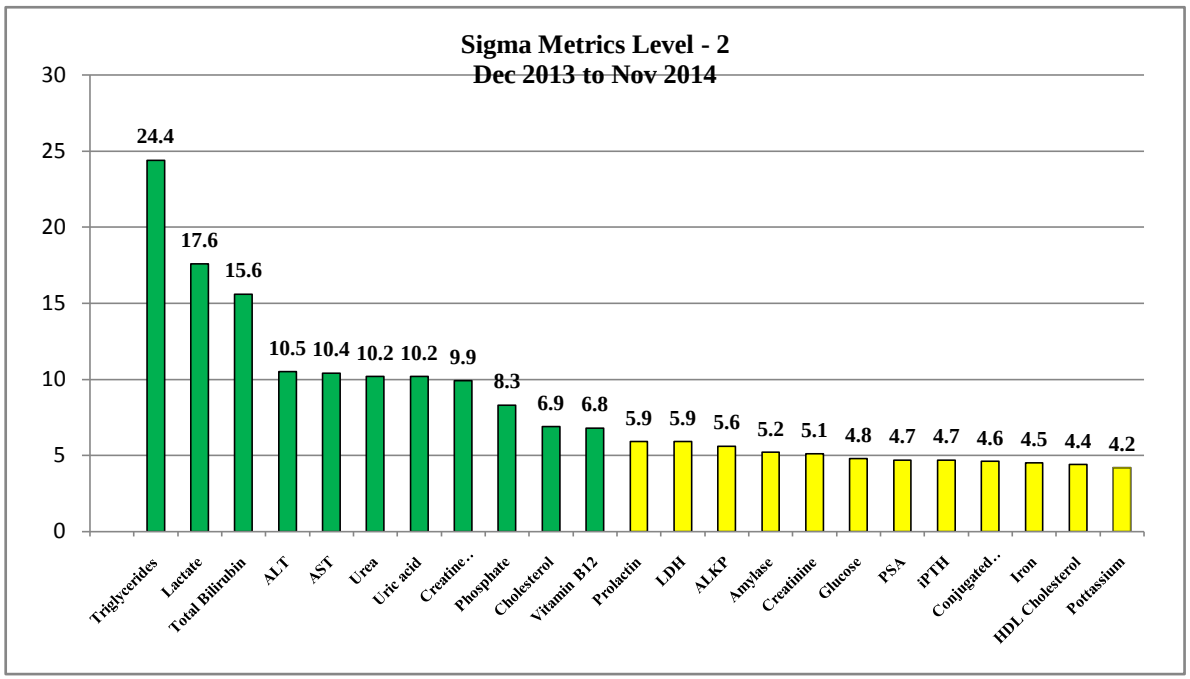

Table 6: Total Analytical Error Level – 1 (Monthly wise Dec 2013 – Nov 2014)

Analyte	Dec 2013	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014
Amylase	19	23.8	6.9528	11.0356	27.3068	17.3582	14.3182	15.34	21.932	16.5176	13.7012	16.7
ALT	40.2222	17.9	14.8496	29.34	19.0482	21.3294	25.6494	27.8714	28.3764	15.4016	18.336	21.2
ALKP	3.8752	9.2	12.2552	8.1	6.664	10.7196	7.2796	6.348	8.027	8.9724	6.736	5.7
AST	7.1648	5.6	6.1274	5.7774	4.6232	3.567	4.627	5.1812	8.5128	8.204	6.3538	9.4
Conjugated bilirubin	41.95	32.3	45.302	33.156	21.058	62.24	72.94	33.63	16.27	70.802	49.638	27.1
Total Bilirubin	7.2906	10.1	8.1584	14.3864	23.8078	18.419	15.559	16.1046	17.7636	11.9538	24.369	31.6
Cholesterol	3.7422	5.5	2.9614	9.6622	2.7762	5.0082	4.0082	6.6512	4.4054	5.687	5.7398	6.4
Creatine kinase (CK)	9.471	14.8	13.2012	14.6352	7.9866	8.4434	13.1234	11.3102	16.0144	7.2962	10.6796	9.0
Creatinine	3.1826	6.0	5.4114	6.4126	8.0408	5.0252	2.9552	3.0702	4.0838	4.9682	5.8486	7.1
Glucose	8.5696	4.2	2.2992	7.3988	2.3558	3.7002	6.2748	3.2682	7.7608	6.3252	4.4286	8.4
HDL Cholesterol	10.854	6.3	8.7948	13.714	11.8702	8.2674	11.3156	6.9192	13.2256	13.944	8.9902	12.0
Iron	12.6828	9.5	9.357	14.0986	18.7222	6.1942	12.173	12.681	13.0796	15.1298	10.8116	22.4
Lactate	2.6226	6.0	4.5542	14.7982	6.4318	3.2248	3.7378	2.3214	5.0758	6.77	4.2436	4.9
LDH	15.3034	12.0	9.3496	19.357	12.4274	17.4234	12.2974	13.3924	9.1312	11.8854	9.9964	12.3
iPTH	15.428	20.4	22.6948	12.5874	18.2134	22.8742	5.8632	14.8708	11.8632	18.1764	37.3924	27.0
Phosphate	4.6008	18.0	4.3678	6.6852	9.8298	3.0918	6.6042	2.9252	4.2378	6.0446	5.7152	4.7
Potassium	3.1908	14.6	9.077	4.2312	8.9776	5.7132	11.9582	1.2646	3.5366	7.9116	3.664	3.1
Prolactin	18.5176	13.3	13.4462	19.0064	25.5492	14.7018	17.2736	23.796	21.522	8.4976	19.9786	10.5
PSA	27.6892	17.8	32.7816	23.9244	15.4458	13.5266	4.4672	41.9264	23.0716	25.3722	32.9822	30.4
Triglycerides	2.1588	11.4	2.3414	4.3482	3.4382	4.5886	2.0416	2.1902	7.4462	4.1252	3.0808	9.7
Uric acid	4.1528	2.6	3.7816	5.1692	2.57	2.6362	3.7032	5.0094	2.9282	2.5866	3.9474	6.8
Urea	8.1018	10.7	3.763	7.3618	8.754	5.9758	6.2406	5.299	6.0478	4.1696	14.8304	4.4
Vitamin B12	10.6566	11.8	18.7628	28.9774	18.7454	38.112	15.0762	9.8566	21.6132	6.77	16.1272	15.7

Table 7: Total Analytical Error Level – 2 (Monthly wise Dec 2013 – Nov 2014)

Analyte	Dec 2013	Jan 2014	Feb 2014	March 2014	April 2014	May 2014	June 2014	July 2014	Aug 2014	Sep 2014	Oct 2014	Nov 2014
Amylase	10.6444	20.123	2.8938	4.3432	20.4362	13.3784	9.5266	7.024	10.6658	12.32	9.4046	12.624
ALT	29.6094	6.7096	8.1176	20.3112	7.6632	5.8854	12.6408	13.7738	11.5464	6.2342	9.8418	4.7666
ALKP	4.2712	9.5594	11.1464	7.3476	3.793	10.5612	6.9826	5.3382	6.3638	5.8242	6.241	5.6972
AST	6.0956	4.817	6.4046	5.0646	4.148	3.666	3.439	5.8346	7.4436	8.3426	5.4232	9.2468
Conju. bilirubin	30.9214	30.15	37.481	23.0184	12.544	52.3004	63.0598	41.7876	18.151	56.0708	46.371	28.5122
Total Bilirubin	3.885	6.2488	5.6834	11.0204	16.4818	12.6374	9.0448	9.927	12.5562	8.8848	14.4492	24.9948
Cholesterol	3.8808	8.426	3.199	7.801	2.4396	3.7608	3.5924	5.5226	3.8114	6.1028	5.2052	5.193
Creatine kinase	14.025	15.841	15.7356	23.8224	7.2144	8.0474	14.0144	5.3306	12.5296	5.3756	9.9272	7.3882
Creatinine	2.7866	6.4406	7.0152	5.779	9.1298	5.8172	3.965	5.8818	3.8264	6.0968	6.5614	7.0036
Glucose	8.629	5.441	3.0318	3.2804	2.4152	4.3734	6.1758	3.5256	6.4342	7.0776	5.2602	8.3012
HDL Cholesterol	10.9134	5.1436	7.7652	12.3478	10.2862	6.4062	6.9992	3.6918	10.5526	13.449	7.1884	7.9696
Iron	18.1476	11.801	19.0392	19.801	26.1868	12.748	25.241	27.5508	23.4746	20.456	23.345	36.9512
Lactate	5.157	8.3272	5.7422	16.4812	5.6398	3.304	4.6288	3.8064	7.4518	8.7896	4.6792	8.5354
LDH	11.3632	6.7786	5.5282	10.6846	5.7152	11.0676	8.3968	7.1554	6.0226	7.272	4.8682	6.8126
iPTH	28.496	17.1946	17.7844	19.1808	21.6388	25.2106	25.584	16.0192	26.1984	16.731	26.7796	9.4172
Phosphate	5.571	15.5758	4.8628	7.5366	9.4734	2.7552	8.0892	2.7866	2.7726	4.52	5.7152	4.4918
Potassium	3.0324	10.201	9.275	4.0728	9.9082	6.3864	1.8206	1.4626	4.1504	7.9512	3.1294	2.961
Prolactin	30.4372	13.7274	18.8516	11.6408	14.6988	17.5728	14.0066	19.7964	21.72	14.5366	16.8502	19.1512
PSA	26.7982	5.0316	33.9696	27.7062	24.5736	11.7842	23	39.095	29.4472	21.3726	28.3094	22.4728
Triglycerides	2.238	15.1392	2.0444	4.2096	6.3488	4.9252	2.7148	3.3188	7.4066	5.9666	2.3284	10.624
Uric acid	4.6874	3.9856	4.3954	5.1494	4.649	3.547	3.327	4.4748	2.7302	3.4182	4.2048	6.9804
Urea	6.9534	9.8336	4.3966	6.055	7.5462	5.065	4.8546	6.6652	6.9388	4.2884	15.2066	3.6766
Vitamin B12	8.9142	9.7766	18.7826	14.6818	5.3012	33.3798	15.3336	15.757	18.3264	16.7096	17.2558	13.1946

Table 8: Example of A QC design based on sigma metrics

Sigma	Westgard Rule	Levels	Measurements	P Error Detection	P False Rejection
6.0	1 3.5s	2	1	0.98	0.01
5.8	1 3.5s	2	1	0.98	0.00
5.6	1 3s	2	1	0.97	0.00
5.4	1 3s	2	1	0.94	0.00
5.2	1 3s	2	1	0.91	0.00
5.0	1 2.5s	2	1	0.96	0.03
4.8	1 2.5s	2	1	0.93	0.03
4.6	1 3s	2	1	0.92	0.01
4.4	1 2.5s	2	1	0.96	0.04
4.2	1 2.5s	2	1	0.92	0.04
4.0	1 3s/2 2s/R 4s/4 1s	2	2	0.91	0.03
3.8	1 3s/2 2s/R 4s/4 1s	2	2	0.86	0.03
3.6	1 3s/2 2s/R 4s/4 1s	2	2	0.79	0.03
3.4	1 3s/2 2s/R 4s/4 1s	2	2	0.65	0.03
3.2	1 3s/2 2s/R 4s/4 1s	3	2	0.48	0.03
3.0	1 3s/2 2s/R 4s/4 1s	3	2	0.36	0.02

5. Conclusion

Out of 23 analytes evaluated for six sigma assessment 11 parameters that is Lactate, Triglycerides, Uric acid, Iron, AST, Urea, Creatinine kinase, Phosphate, Prolactin, Total Bilirubin, Creatinine showed the sigma value of more than 6.0, Cholesterol, Vitamin B12, Glucose, iPTH, ALKP, PSA, Potassium, Conjugated bilirubin, ALT, HDL Cholesterol showed the performance between 3 and 6 and LDH, Amylase showed the performance below 3.0 in level 1. Sigma scale on level 2 showed Triglycerides, Lactate, Total Bilirubin, ALT, AST, Uric acid, Urea, Creatinine kinase, Phosphate, Cholesterol, Vitamin B12 with the performance of above six sigma and Prolactin, LDH, ALKP, Amylase, Creatinine, Glucose, Conjugated bilirubin, PSA, iPTH, Iron, HDL Cholesterol, Potassium with the performance between 3 and 6. So it is the need of the hour to implement the Sigma metrics with the help of IQC and EQAS and combining Sigma metrics with QC Design tools, such as the Operating Specifications chart (OPSpecs), allows the laboratory to customize and optimize the QC procedures. A rational QC Design can eliminate much of the wasteful 2s QC practices, replacing them instead with appropriate control limits and numbers of control measurements.

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