USE OF STATISTICAL PROCESS CONTROL FOR THE PLANT, NETWORK & ETS

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Introduction

In this presentation we will look into the use of Statistical Process Control in District Cooling Industry. Our focus today is on the use of Standard Deviation, Multiple Linear Regression and Harmonic Mean. We will be seeing the use of Control Charts as part of the Standard Deviation.

These will help us meet our Supply water temperature commitments to our clients, monitor the performance of Flow Control Valves and help in limiting the flow rate to our customers with in the Contractual flow.

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Why ?

1

Need for newer Key Performance Indicators in District Cooling

While Kw/Ton and Gal/Ton are good performance measures we need to have one for Plant Supply Temperature compliance and ETS Flow Control Valve Compliance

2

Use of Statistical Process Control

Measures such as Standard deviation is good enough when it comes to provide a measure for deviations.

What ?

3

What is Standard Deviation ?

The **standard deviation** is a statistic that measures the dispersion of a dataset relative to its mean and is calculated as the square root of the variance.

How ?

4

How Standard Deviation is used ?

We use SD to find out the deviation of the Process Values Such as ‘Plant Supply Temperature’, ‘ETS Return water Temperature’ against the set points

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Plant Supply Temperature

Case Study – BBET Plant

For the purpose of understanding we have taken the supply temperatures of our BBET plant for 7 days at 3 minutes interval. The Standard Deviation calculation was done and a Control Chart was constructed to see whether the process is in Control or not

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SAMPLE TIME	BBET PLANT HEADER SUPPLY TEMP (X)	SP ($\bar{X}$) = 40.1°F	(SP-Actual)	(SP-Actual)²
11/28/18 0:00	39.53	40.10	0.57	0.33
11/28/18 0:03	39.27	40.10	0.83	0.69
11/28/18 0:06	39.27	40.10	0.83	0.69
11/28/18 0:09	39.27	40.10	0.83	0.69
11/28/18 0:12	39.27	40.10	0.83	0.69
11/28/18 0:15	39.27	40.10	0.83	0.69
11/28/18 0:18	39.34	40.10	0.76	0.58
11/28/18 0:21	39.34	40.10	0.76	0.58
11/28/18 0:24	39.34	40.10	0.76	0.58
11/28/18 0:27	39.34	40.10	0.76	0.58
11/28/18 0:30	39.34	40.10	0.76	0.58
11/28/18 0:33	39.27	40.10	0.83	0.69
11/28/18 0:36	39.27	40.10	0.83	0.69
11/28/18 0:39	39.27	40.10	0.83	0.69
11/28/18 0:42	39.27	40.10	0.83	0.69
11/28/18 0:45	39.27	40.10	0.83	0.69
11/28/18 0:48	39.23	40.10	0.87	0.75
11/28/18 0:51	39.23	40.10	0.87	0.75
11/28/18 0:54	39.23	40.10	0.87	0.75
11/28/18 0:57	39.23	40.10	0.87	0.75
11/28/18 1:00	39.23	40.10	0.87	0.75
11/28/18 1:03	39.28	40.10	0.82	0.68
11/28/18 1:06	39.28	40.10	0.82	0.68
11/28/18 1:09	39.28	40.10	0.82	0.68
11/28/18 1:12	39.28	40.10	0.82	0.68
11/28/18 1:15	39.28	40.10	0.82	0.68
11/28/18 1:18	39.20	40.10	0.90	0.81
11/28/18 1:21	39.20	40.10	0.90	0.81
11/28/18 1:24	39.20	40.10	0.90	0.81
11/28/18 1:27	39.20	40.10	0.90	0.81
11/28/18 1:30	39.20	40.10	0.90	0.81
11/28/18 1:33	39.30	40.10	0.80	0.64
11/28/18 1:36	39.30	40.10	0.80	0.64
11/28/18 1:39	39.30	40.10	0.80	0.64
11/28/18 1:42	39.30	40.10	0.80	0.64
11/28/18 1:45	39.30	40.10	0.80	0.64
11/28/18 1:48	39.21	40.10	0.89	0.79

SAMPLE TIME	BBET PLANT HEADER SUPPLY TEMP (X)	SP ($\bar{X}$) = 40.1°F	(SP-Actual)	(SP-Actual)²
12/4/18 22:12	39.17	40.10	0.93	0.86
12/4/18 22:15	39.17	40.10	0.93	0.86
12/4/18 22:18	39.19	40.10	0.91	0.83
12/4/18 22:21	39.19	40.10	0.91	0.83
12/4/18 22:24	39.19	40.10	0.91	0.83
12/4/18 22:27	39.19	40.10	0.91	0.83
12/4/18 22:30	39.19	40.10	0.91	0.83
12/4/18 22:33	39.20	40.10	0.90	0.81
12/4/18 22:36	39.20	40.10	0.90	0.81
12/4/18 22:39	39.20	40.10	0.90	0.81
12/4/18 22:42	39.20	40.10	0.90	0.81
12/4/18 22:45	39.20	40.10	0.90	0.81
12/4/18 22:48	39.20	40.10	0.90	0.81
12/4/18 22:51	39.20	40.10	0.90	0.81
12/4/18 22:54	39.20	40.10	0.90	0.81
12/4/18 22:57	39.20	40.10	0.90	0.81
12/4/18 23:00	39.20	40.10	0.90	0.81
12/4/18 23:03	39.20	40.10	0.90	0.81
12/4/18 23:06	39.20	40.10	0.90	0.81
12/4/18 23:09	39.20	40.10	0.90	0.81
12/4/18 23:12	39.20	40.10	0.90	0.81
12/4/18 23:15	39.20	40.10	0.90	0.81
12/4/18 23:18	39.17	40.10	0.93	0.86
12/4/18 23:21	39.17	40.10	0.93	0.86
12/4/18 23:24	39.17	40.10	0.93	0.86
12/4/18 23:27	39.17	40.10	0.93	0.86
12/4/18 23:30	39.17	40.10	0.93	0.86
12/4/18 23:33	39.14	40.10	0.96	0.92
12/4/18 23:36	39.14	40.10	0.96	0.92
12/4/18 23:39	39.14	40.10	0.96	0.92
12/4/18 23:42	39.14	40.10	0.96	0.92
12/4/18 23:45	39.14	40.10	0.96	0.92
12/4/18 23:48	39.20	40.10	0.90	0.80
12/4/18 23:51	39.20	40.10	0.90	0.80
12/4/18 23:54	39.20	40.10	0.90	0.80
12/4/18 23:57	39.20	40.10	0.90	0.80
12/5/18 0:00	39.20	40.10	0.90	0.80

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** 40.1°F is the Set point – Commitment to the Customer*

$$\sum |x - \bar{x}|^2$$ 1550

$$\frac{\sum |x - \bar{x}|^2}{n - 1}$$ 0.4613

$$\mathrm{SD}_{\mathrm{sample}} = \sqrt{\frac{\sum |x - \bar{x}|^2}{n - 1}}$$ **0.6791**

Where ‘n’ the number of Samples = 3361

Though $\bar{x}$ is mean, we use Set Point 40.1ºF since we wanted to find deviations from Set point

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A Standard deviation has got ‘unit of measurement’ which is same as that of sample data. In this case it ^{o}F.

So a Standard Deviation of $0.6791^{o}F$ means we supply Chilled water to our customer at $40.1^{o}F \pm 0.67^{o}F$ which is well within our commitment of ($40.1^{o}F \pm 1.8^{o}F$) to our customer.

So now we have a quantitative measure that we can share with our Customers to prove our commitments.

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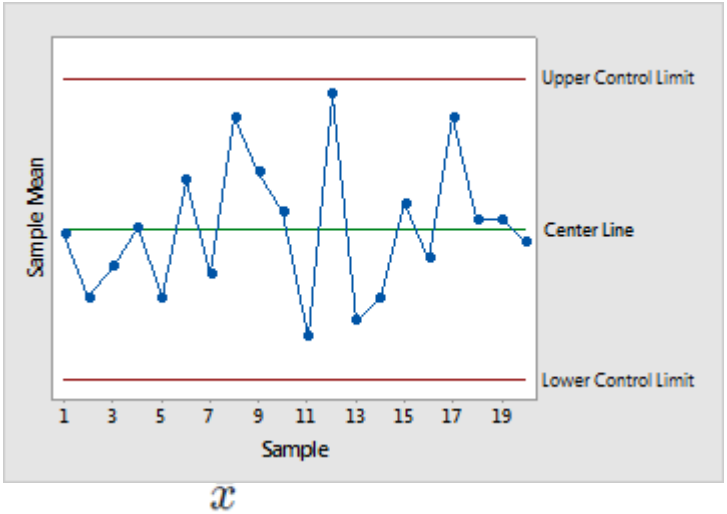
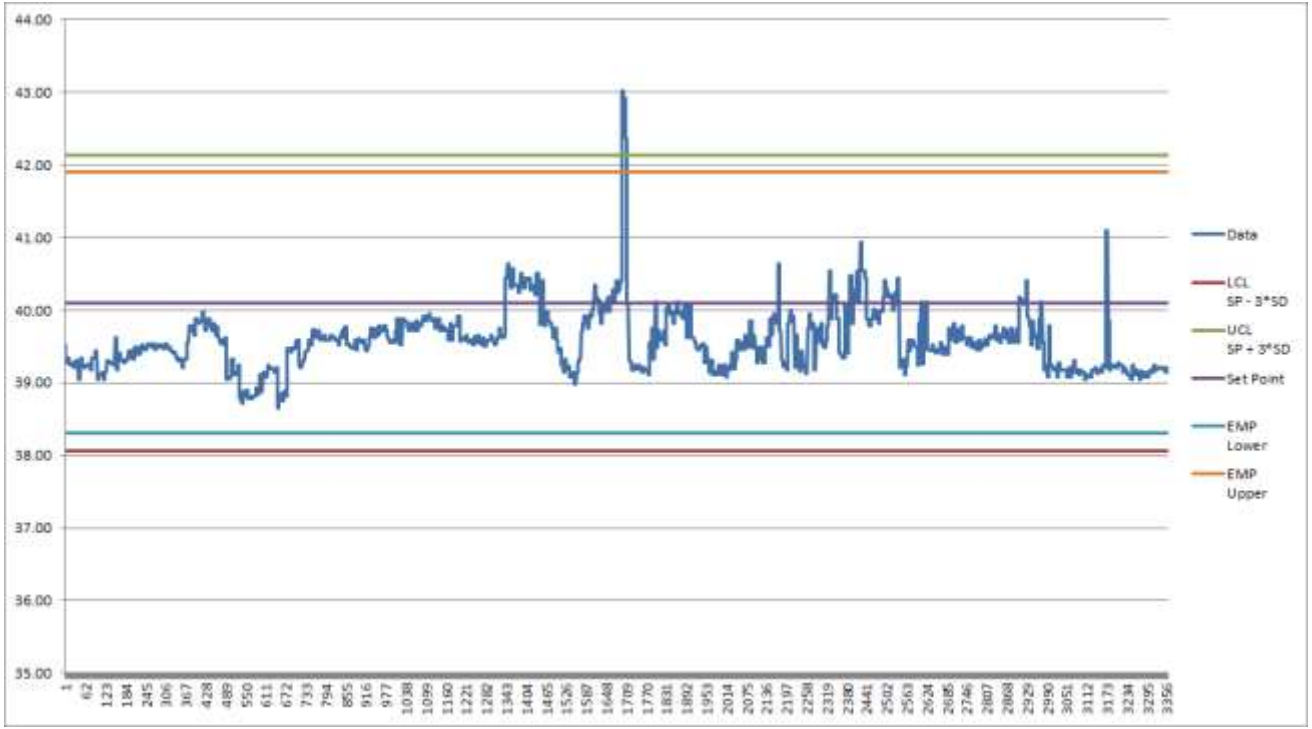
The **control chart** is a graph used to study how a process changes over time. Data are plotted in time order. A control chart always has a central line for the average (Set point), an upper line for the upper **control** limit (3σ) and a lower line for the lower **control** limit (-3σ). These lines are determined from historical data.



S.No	Data	LCL SP - 3*SD	UCL SP + 3*SD	Set Point
1	39.25	36.32373	40.27627	38.3
2	39.25	36.32373	40.27627	38.3
3	39.27	36.32373	40.27627	38.3
4	39.32	36.32373	40.27627	38.3
5	39.42	36.32373	40.27627	38.3
6	39.38	36.32373	40.27627	38.3
7	39.32	36.32373	40.27627	38.3
8	39.27	36.32373	40.27627	38.3
9	39.23	36.32373	40.27627	38.3
10	39.20	36.32373	40.27627	38.3
11	39.12	36.32373	40.27627	38.3
12	39.04	36.32373	40.27627	38.3
13	39.03	36.32373	40.27627	38.3
14	39.03	36.32373	40.27627	38.3
15	39.04	36.32373	40.27627	38.3
16	39.06	36.32373	40.27627	38.3
17	39.09	36.32373	40.27627	38.3
18	39.11	36.32373	40.27627	38.3
19	39.11	36.32373	40.27627	38.3
20	39.10	36.32373	40.27627	38.3
21	39.11	36.32373	40.27627	38.3
22	39.12	36.32373	40.27627	38.3
23	39.12	36.32373	40.27627	38.3
24	39.13	36.32373	40.27627	38.3
25	39.13	36.32373	40.27627	38.3
26	39.16	36.32373	40.27627	38.3
27	39.18	36.32373	40.27627	38.3
28	39.12	36.32373	40.27627	38.3
29	39.09	36.32373	40.27627	38.3
30	39.09	36.32373	40.27627	38.3
31	39.10	36.32373	40.27627	38.3
32	39.10	36.32373	40.27627	38.3

S.No	Data	LCL SP - 3*SD	UCL SP + 3*SD	Set Point
3330	39.19	38.1	42.1	40.1
3331	39.19	38.1	42.1	40.1
3332	39.20	38.1	42.1	40.1
3333	39.20	38.1	42.1	40.1
3334	39.20	38.1	42.1	40.1
3335	39.20	38.1	42.1	40.1
3336	39.20	38.1	42.1	40.1
3337	39.20	38.1	42.1	40.1
3338	39.20	38.1	42.1	40.1
3339	39.20	38.1	42.1	40.1
3340	39.20	38.1	42.1	40.1
3341	39.20	38.1	42.1	40.1
3342	39.20	38.1	42.1	40.1
3343	39.20	38.1	42.1	40.1
3344	39.20	38.1	42.1	40.1
3345	39.20	38.1	42.1	40.1
3346	39.20	38.1	42.1	40.1
3347	39.17	38.1	42.1	40.1
3348	39.17	38.1	42.1	40.1
3349	39.17	38.1	42.1	40.1
3350	39.17	38.1	42.1	40.1
3351	39.17	38.1	42.1	40.1
3352	39.14	38.1	42.1	40.1
3353	39.14	38.1	42.1	40.1
3354	39.14	38.1	42.1	40.1
3355	39.14	38.1	42.1	40.1
3356	39.14	38.1	42.1	40.1
3357	39.20	38.1	42.1	40.1
3358	39.20	38.1	42.1	40.1
3359	39.20	38.1	42.1	40.1
3360	39.20	38.1	42.1	40.1
3361	39.20	38.1	42.1	40.1

Now with the sample data and calculated Standard Deviation let us plot the Control Chart



* It is important to note here that the Center Line is not the mean but the ‘Set Point’ which is 40.1ºF

ETS HEX Valve Performance

Case Study

For the purpose of understanding we have taken the Return temperatures of one of the HEX in an ETS in our BBET Network for a day at 3 minutes interval. The Standard Deviation calculation was done and a Control Chart was constructed to see whether the process is in Control or not

DATE AND TIME	HEX 1 Return Temperature (X)	(SP-Actual) SP($\bar{X}$) = 55.9°F	(SP-Actual)²
31-Jan-17 00:00:00	56.82	1.342	1.801
31-Jan-17 00:03:00	57.00	1.792	3.211
31-Jan-17 00:06:00	57.18	2.307	5.322
31-Jan-17 00:09:00	57.27	2.560	6.554
31-Jan-17 00:12:00	57.34	2.796	7.816
31-Jan-17 00:15:00	57.41	3.042	9.252
31-Jan-17 00:18:00	57.48	3.298	10.878
31-Jan-17 00:21:00	57.55	3.565	12.708
31-Jan-17 00:24:00	57.53	3.464	12.000
31-Jan-17 00:27:00	57.49	3.331	11.099
31-Jan-17 00:30:00	57.46	3.201	10.249
31-Jan-17 00:33:00	57.42	3.074	9.450
31-Jan-17 00:36:00	57.38	2.949	8.698
31-Jan-17 00:39:00	57.22	2.402	5.771
31-Jan-17 00:42:00	57.04	1.876	3.520
31-Jan-17 00:45:00	56.86	1.415	2.002
31-Jan-17 00:48:00	56.68	1.019	1.038
31-Jan-17 00:51:00	56.49	0.687	0.472
31-Jan-17 00:54:00	56.22	0.303	0.092
31-Jan-17 00:57:00	55.93	0.069	0.005
31-Jan-17 01:00:00	55.64	0.001	0.000
31-Jan-17 01:03:00	55.35	0.098	0.010
31-Jan-17 01:06:00	55.07	0.361	0.130
31-Jan-17 01:09:00	54.84	0.677	0.459
31-Jan-17 01:12:00	54.63	1.080	1.165
31-Jan-17 01:15:00	54.41	1.575	2.481
31-Jan-17 01:18:00	54.19	2.164	4.683
31-Jan-17 01:21:00	53.98	2.846	8.101
31-Jan-17 01:24:00	53.93	3.023	9.141
31-Jan-17 01:27:00	53.89	3.150	9.922
31-Jan-17 01:30:00	53.85	3.279	10.753
31-Jan-17 01:33:00	53.82	3.411	11.635
31-Jan-17 01:36:00	53.78	3.546	12.571
31-Jan-17 01:39:00	53.95	2.960	8.764

DATE AND TIME	HEX 1 Return Temperature (X)	(SP-Actual) SP($\bar{X}$) = 55.9°F	(SP-Actual)²
31-Jan-17 22:24:00	57.26	2.541	6.457
31-Jan-17 22:27:00	56.94	1.614	2.605
31-Jan-17 22:30:00	56.61	0.896	0.804
31-Jan-17 22:33:00	56.29	0.388	0.151
31-Jan-17 22:36:00	55.97	0.090	0.008
31-Jan-17 22:39:00	55.71	0.002	0.000
31-Jan-17 22:42:00	55.46	0.044	0.002
31-Jan-17 22:45:00	55.20	0.214	0.046
31-Jan-17 22:48:00	54.95	0.511	0.261
31-Jan-17 22:51:00	54.70	0.936	0.876
31-Jan-17 22:54:00	54.51	1.328	1.764
31-Jan-17 22:57:00	54.33	1.775	3.150
31-Jan-17 23:00:00	54.15	2.286	5.227
31-Jan-17 23:03:00	53.97	2.862	8.192
31-Jan-17 23:06:00	53.79	3.503	12.270
31-Jan-17 23:09:00	53.75	3.683	13.563
31-Jan-17 23:12:00	53.71	3.822	14.610
31-Jan-17 23:15:00	53.67	3.965	15.718
31-Jan-17 23:18:00	53.64	4.109	16.887
31-Jan-17 23:21:00	53.60	4.257	18.120
31-Jan-17 23:24:00	53.73	3.735	13.949
31-Jan-17 23:27:00	53.88	3.199	10.233
31-Jan-17 23:30:00	54.02	2.705	7.315
31-Jan-17 23:33:00	54.17	2.252	5.070
31-Jan-17 23:36:00	54.31	1.840	3.387
31-Jan-17 23:39:00	54.55	1.238	1.533
31-Jan-17 23:42:00	54.81	0.741	0.549
31-Jan-17 23:45:00	55.06	0.371	0.137
31-Jan-17 23:48:00	55.31	0.127	0.016
31-Jan-17 23:51:00	55.56	0.011	0.000
31-Jan-17 23:54:00	55.78	0.013	0.000
31-Jan-17 23:57:00	56.00	0.109	0.012
01-Feb-17 00:00:00	56.21	0.298	0.089

** 55.9°F is the Set point*

$$\sum |x - \bar{x}|^2$$ **966.58**

$$\frac{\sum |x - \bar{x}|^2}{n - 1}$$ **2.014**

$$\mathrm{SD}_{\mathrm{sample}} = \sqrt{\frac{\sum |x - \bar{x}|^2}{n - 1}}$$ **1.419**

Where ‘n’ the number of Samples = 481

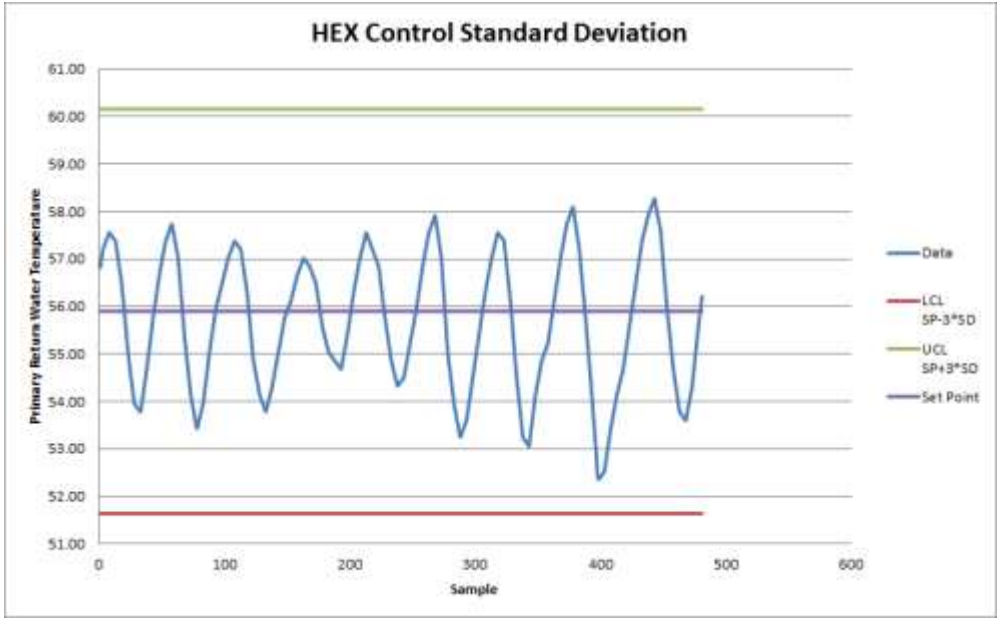
Though $\bar{x}$ is mean, we use Set Point 55.9°F since we wanted to find deviations from Set point

S.NO	Data	LCL SP-3*SD	UCL SP+3*SD	Set Point
1	56.82	51.64285	60.15715	55.9
2	57.00	51.64285	60.15715	55.9
3	57.18	51.64285	60.15715	55.9
4	57.27	51.64285	60.15715	55.9
5	57.34	51.64285	60.15715	55.9
6	57.41	51.64285	60.15715	55.9
7	57.48	51.64285	60.15715	55.9
8	57.55	51.64285	60.15715	55.9
9	57.53	51.64285	60.15715	55.9
10	57.49	51.64285	60.15715	55.9
11	57.46	51.64285	60.15715	55.9
12	57.42	51.64285	60.15715	55.9
13	57.38	51.64285	60.15715	55.9
14	57.22	51.64285	60.15715	55.9
15	57.04	51.64285	60.15715	55.9
16	56.88	51.64285	60.15715	55.9
17	56.68	51.64285	60.15715	55.9
18	56.49	51.64285	60.15715	55.9
19	56.22	51.64285	60.15715	55.9
20	55.93	51.64285	60.15715	55.9
21	55.64	51.64285	60.15715	55.9
22	55.35	51.64285	60.15715	55.9
23	55.07	51.64285	60.15715	55.9
24	54.84	51.64285	60.15715	55.9
25	54.63	51.64285	60.15715	55.9
26	54.41	51.64285	60.15715	55.9
27	54.19	51.64285	60.15715	55.9
28	53.98	51.64285	60.15715	55.9
29	53.93	51.64285	60.15715	55.9
30	53.89	51.64285	60.15715	55.9
31	53.85	51.64285	60.15715	55.9
32	53.82	51.64285	60.15715	55.9
33	53.78	51.64285	60.15715	55.9
34	53.95	51.64285	60.15715	55.9
35	54.13	51.64285	60.15715	55.9
36	54.30	51.64285	60.15715	55.9
37	54.48	51.64285	60.15715	55.9
38	54.66	51.64285	60.15715	55.9
39	54.88	51.64285	60.15715	55.9
40	55.09	51.64285	60.15715	55.9
41	55.31	51.64285	60.15715	55.9

$\bar{x}$

S.NO	Data	LCL SP-3*SD	UCL SP+3*SD	Set Point
449	57.26	51.64285	60.15715	55.9
450	56.94	51.64285	60.15715	55.9
451	56.61	51.64285	60.15715	55.9
452	56.29	51.64285	60.15715	55.9
453	55.97	51.64285	60.15715	55.9
454	55.71	51.64285	60.15715	55.9
455	55.46	51.64285	60.15715	55.9
456	55.20	51.64285	60.15715	55.9
457	54.95	51.64285	60.15715	55.9
458	54.70	51.64285	60.15715	55.9
459	54.51	51.64285	60.15715	55.9
460	54.33	51.64285	60.15715	55.9
461	54.15	51.64285	60.15715	55.9
462	53.97	51.64285	60.15715	55.9
463	53.79	51.64285	60.15715	55.9
464	53.75	51.64285	60.15715	55.9
465	53.71	51.64285	60.15715	55.9
466	53.67	51.64285	60.15715	55.9
467	53.64	51.64285	60.15715	55.9
468	53.60	51.64285	60.15715	55.9
469	53.73	51.64285	60.15715	55.9
470	53.88	51.64285	60.15715	55.9
471	54.02	51.64285	60.15715	55.9
472	54.17	51.64285	60.15715	55.9
473	54.31	51.64285	60.15715	55.9
474	54.55	51.64285	60.15715	55.9
475	54.81	51.64285	60.15715	55.9
476	55.06	51.64285	60.15715	55.9
477	55.31	51.64285	60.15715	55.9
478	55.56	51.64285	60.15715	55.9
479	55.78	51.64285	60.15715	55.9
480	56.00	51.64285	60.15715	55.9
481	56.21	51.64285	60.15715	55.9

Now with the sample data and calculated Standard Deviation let us plot the Control Chart



* It is important to note here that the Center Line is not the mean but the ‘Set Point’ which is 55.9^{o}F

Multi Variable Linear Regression

What is Multi Variable Linear Regression?

Multiple Regression is one form of predictive analysis which explains the relationship between one continuous dependent variable with two or more independent variables

How is it used ?

ETS Return Header Temperature can be predicted using other independent variables such as flow, Valve opening and Secondary side temperatures – Based on the model generated using the historical data

10 Days data of a 2 HEX ETS used for arriving Regression Analysis (16th November – 25th November)

							HEX-1						HEX-2					
Date-Time		BTU METER			ETS HEADER		Primary Side				SECONDARY SIDE		Primary Side				SECONDARY SIDE	
Date	Time (HR)	Header Return Temp. (°F)	Header Supply Temp. (°F)	Flow rate (GPM)	Supply Press. (PSI)	Return Press. (PSI)	Return Water Temp (°F)	Supply Press. (PSI)	Return Press. (PSI)	Valve Position A (%)	Sec.Supply Temp (°F)	Sec.Return Temp (°F)	Return Water Temp (°F)	Supply Press. (PSI)	Return Press. (PSI)	Valve Position A (%)	Sec.Supply Temp (°F)	Sec.Return Temp (°F)
11/16/18 12:00 AM	0:00	57.42	40.04	103.34	39.61	33.85	57.42	43.84	34.94	17.99	53.02	57.55	57.61	43.69	35.14	27.37	50.41	57.85
	1:00	57.26	40.09	107.42	39.69	33.90	57.34	43.79	35.08	18.04	53.32	57.45	57.51	43.76	35.23	25.63	50.46	57.74
	2:00	57.31	40.15	108.97	39.62	33.99	57.34	43.83	35.09	18.08	53.41	57.44	57.47	43.79	35.32	26.69	50.26	57.74
	3:00	57.07	40.12	123.77	39.81	34.68	57.11	43.92	35.77	18.90	53.43	57.24	57.19	43.82	36.05	30.15	49.11	57.47
	4:00	57.14	40.12	149.53	39.56	35.58	57.18	43.70	36.73	22.82	52.50	57.17	57.11	43.51	36.96	36.74	47.48	57.45
	5:00	56.60	40.04	157.81	39.49	35.88	56.70	43.63	37.00	23.33	52.02	56.65	56.48	43.49	37.31	38.35	46.05	56.96
	6:00	56.11	40.14	150.60	39.26	35.21	56.23	43.42	36.32	21.26	52.19	56.23	56.08	43.27	36.53	35.49	46.35	56.51
	7:00	55.77	40.07	140.01	41.29	37.05	55.83	45.46	38.27	20.48	51.73	55.86	55.68	45.36	38.49	34.40	45.80	56.16
	8:00	55.32	40.10	127.75	42.63	37.57	55.32	46.78	38.69	19.55	51.28	55.26	55.21	46.72	38.94	30.09	46.83	55.57
	9:00	55.97	40.02	115.71	42.97	37.55	55.99	47.29	38.79	18.06	52.19	56.12	56.17	47.24	38.94	27.88	48.64	56.41
	10:00	56.55	40.06	127.14	43.51	38.45	56.57	47.60	39.71	19.05	52.32	56.63	56.57	47.56	39.87	30.54	47.24	56.92
11/25/18 3:00 PM	15:00	55.36	41.07	98.38	44.01	34.49	55.39	48.12	35.57	17.99	50.11	55.61	55.64	48.17	35.84	19.09	50.29	55.89
	16:00	56.38	40.24	92.56	43.85	34.34	56.53	48.07	35.51	17.98	50.34	56.66	56.72	47.99	35.78	19.07	50.63	56.95
	17:00	56.39	40.14	98.48	43.73	34.24	56.41	47.90	35.41	17.99	50.70	56.59	56.65	47.85	35.60	19.03	50.97	56.81
	18:00	57.21	40.16	111.47	44.76	34.81	57.16	48.88	35.91	18.00	51.01	57.39	57.41	48.92	36.17	21.31	50.33	57.62
	19:00	57.14	40.11	102.26	44.58	34.23	57.17	48.70	35.37	18.00	50.11	57.27	57.41	48.76	35.39	25.49	50.46	57.53
	20:00	56.11	40.22	86.99	40.28	32.72	56.06	44.35	33.88	17.99	50.02	56.21	56.31	44.35	34.11	19.03	50.30	56.48
	21:00	54.80	40.21	92.27	42.06	33.42	54.83	45.98	34.65	17.98	49.02	55.06	55.09	46.04	34.88	19.07	49.26	55.28
	22:00	54.24	40.18	104.89	41.70	33.70	54.17	45.86	34.89	19.24	47.63	54.29	54.36	45.73	35.07	20.97	47.43	54.64
	23:00	54.29	40.18	128.19	41.69	35.02	54.19	45.90	36.23	23.07	46.75	54.48	54.27	45.76	36.37	24.82	46.56	54.81

Dependent Variable

Output of the Model – Generated in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adjusted R Square	1.00
Standard Error	0.05
Observations	240.00

Very good linear relationship

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	16.00	262.70	16.42	5993.25	0.00
Residual	223.00	0.61	0.00		
Total	239.00	263.31			

		Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
C	Intercept	1.00	0.63	1.59	0.11	-0.24	2.23	-0.24	2.23
M1	Header Supply Temp. (°F)	-0.01	0.01	-0.64	0.52	-0.03	0.02	-0.03	0.02
M2	Flow rate (GPM)	0.00	0.00	1.86	0.06	0.00	0.00	0.00	0.00
M3	Supply Press. (PSI)	0.03	0.06	0.44	0.66	-0.10	0.15	-0.10	0.15
M4	Return Press. (PSI)	-0.03	0.05	-0.67	0.50	-0.12	0.06	-0.12	0.06
M5	Return Water Temp (°F)	0.69	0.06	10.74	0.00	0.56	0.82	0.56	0.82
M6	Supply Press. (PSI)	-0.05	0.07	-0.68	0.50	-0.19	0.09	-0.19	0.09
M7	Return Press. (PSI)	0.02	0.05	0.40	0.69	-0.08	0.12	-0.08	0.12
M8	Valve Position A (%)	0.00	0.01	-0.70	0.49	-0.02	0.01	-0.02	0.01
M9	Sec.Supply Temp (°F)	-0.03	0.01	-2.11	0.04	-0.05	0.00	-0.05	0.00
M10	Sec.Return Temp (°F)	-0.28	0.08	-3.37	0.00	-0.44	-0.12	-0.44	-0.12
M11	Return Water Temp (°F)	0.42	0.05	7.88	0.00	0.32	0.53	0.32	0.53
M12	Supply Press. (PSI)	0.02	0.07	0.28	0.78	-0.12	0.16	-0.12	0.16
M13	Return Press. (PSI)	0.01	0.06	0.20	0.84	-0.11	0.13	-0.11	0.13
M14	Valve Position A (%)	0.00	0.00	0.70	0.49	-0.01	0.01	-0.01	0.01
M15	Sec.Supply Temp (°F)	0.00	0.01	-0.35	0.73	-0.03	0.02	-0.03	0.02
M16	Sec.Return Temp (°F)	0.18	0.10	1.75	0.08	-0.02	0.38	-0.02	0.38

Y = C + M1*0.01 + M2*0.00 + M3*0.03 + M4*-0.03 + M5*0.69 + M6*-0.05 + M7*0.02 + M8*0.00 + M9*-0.03 + M10*-0.28 + M11*0.42 + M12*0.02 + M13*0.01 + M14*0.00 + M15*0.00 + M16*0.18

The results when the model applied for 26th November and 27th November is as follows…

							HEX-1						HEX-2								
Date-Time		BTU METER			ETS HEADER		Primary Side				SECONDARY SIDE		Primary Side				SECONDARY SIDE				
Date	Time (HR)	Header Return Temp. (°F)	Header Supply Temp. (°F)	Flow rate (GPM)	Supply Press (PSI)	Return Press (PSI)	Return Water Temp (°F)	Supply Press (PSI)	Return Press (PSI)	Valve Position A (%)	Sec.Supply Temp (°F)	Sec.Return Temp (°F)	Return Water Temp (°F)	Supply Press (PSI)	Return Press (PSI)	Valve Position A (%)	Sec.Supply Temp (°F)	Sec.Return Temp (°F)	Predicted Value	Actual Value	%Error
11/26/18 12:00 AM	0:00	54.48	40.12	158.40	41.84	36.41	54.35	45.89	37.58	27.94	45.85	54.58	54.32	45.79	37.84	31.06	45.10	54.97	54.42	54.48	0.10%
	1:00	54.76	40.20	163.00	41.77	36.57	54.67	45.82	37.61	27.89	46.22	54.89	54.65	45.73	37.84	31.33	45.24	55.27	54.74	54.76	0.04%
	2:00	56.39	40.15	170.03	41.88	37.65	56.42	45.91	38.74	29.20	47.23	56.69	56.15	45.84	38.99	35.00	44.71	56.96	56.37	56.39	0.04%
	3:00	57.56	40.20	116.20	41.76	33.66	57.55	45.77	34.83	19.13	51.50	57.64	57.69	45.75	35.07	23.49	49.66	57.90	57.54	57.56	0.02%
	4:00	56.79	40.17	92.62	41.84	32.90	56.69	45.98	34.07	18.02	50.51	56.74	56.89	46.00	34.26	19.08	50.73	57.07	56.72	56.79	0.13%
	5:00	55.87	40.12	97.16	42.85	33.41	55.89	46.97	34.55	17.94	49.90	56.11	56.15	46.98	34.80	19.11	50.14	56.40	55.94	55.87	0.12%
	6:00	54.59	40.25	99.09	42.75	33.09	54.57	46.94	34.20	18.01	48.88	54.78	54.85	46.94	34.41	19.04	49.08	55.06	54.64	54.59	0.09%
	7:00	54.73	40.18	127.69	43.47	35.10	54.57	47.57	36.28	21.31	46.93	54.62	54.68	47.61	36.55	22.93	46.74	54.98	54.67	54.73	0.11%
	8:00	56.56	40.16	97.98	42.33	33.87	56.53	47.60	34.97	18.05	49.11	56.57	56.73	47.59	35.21	19.06	49.36	56.84	56.56	56.56	0.00%
	9:00	54.69	40.18	82.44	40.69	34.89	54.61	44.79	36.05	18.28	48.92	54.66	54.77	44.73	36.33	20.61	48.38	54.94	54.64	54.69	0.09%
	10:00	56.69	40.17	140.26	41.59	38.34	56.88	45.74	39.42	26.57	48.67	56.88	56.35	45.63	39.69	34.30	44.60	57.18	56.71	56.69	0.03%
11/27/18 3:00 PM	15:00	55.66	40.53	91.18	45.65	37.40	55.50	49.70	38.61	17.95	48.59	55.53	55.73	49.73	38.79	19.16	48.74	55.82	55.58	55.66	0.14%
	16:00	56.56	40.53	89.03	45.53	37.27	56.47	49.69	38.53	17.87	49.77	56.54	56.66	49.65	38.69	19.14	49.94	56.85	56.51	56.56	0.08%
	17:00	55.71	40.61	85.92	44.18	36.76	55.58	48.55	37.91	18.03	49.47	55.74	55.81	48.48	38.16	19.07	49.66	55.99	55.61	55.71	0.18%
	18:00	55.66	40.59	96.88	41.67	33.60	55.57	45.76	34.72	18.03	49.24	55.61	55.73	45.75	34.97	20.31	48.57	55.92	55.61	55.66	0.09%
	19:00	55.96	40.55	102.92	41.27	33.60	55.89	45.41	34.73	18.01	49.83	55.93	56.04	45.35	34.94	22.59	47.92	56.21	55.92	55.96	0.08%
	20:00	56.26	40.58	98.99	41.26	33.34	56.19	45.31	34.49	17.98	49.76	56.24	56.34	45.32	34.76	22.27	48.45	56.50	56.23	56.26	0.06%
	21:00	55.78	40.70	99.28	43.84	33.83	55.68	47.94	34.89	18.02	48.54	55.75	55.90	47.96	35.15	19.09	48.83	56.07	55.76	55.78	0.04%
	22:00	55.90	40.90	100.25	43.23	33.20	55.70	47.38	34.32	18.02	48.92	55.68	55.93	47.41	34.54	19.04	49.23	56.00	55.78	55.90	0.22%
	23:00	55.61	40.19	98.87	43.18	33.02	55.51	47.23	34.25	18.04	48.29	55.65	55.75	47.33	34.48	19.06	48.59	55.93	55.60	55.61	0.01%

As you can see the predicted value is almost same as actual value

Harmonic Mean

What is Harmonic Mean?
By Definition Harmonic Mean is the reciprocal of the Arithmetic Mean of the reciprocals of the given set of observations

Example :

Arithmetic mean for (1,3,4,8) is 4

Harmonic Mean is $\frac{4}{\frac{1}{1} + \frac{1}{3} + \frac{1}{4} + \frac{1}{8}}$ = 2.34

How is it used ?

This is used for reducing the impact of the spikes in the flow rate values while monitoring them for restricting flow below contractual values

Thank you

Any Questions ?