Process, Quality and Efficiency Enhancements using LSS

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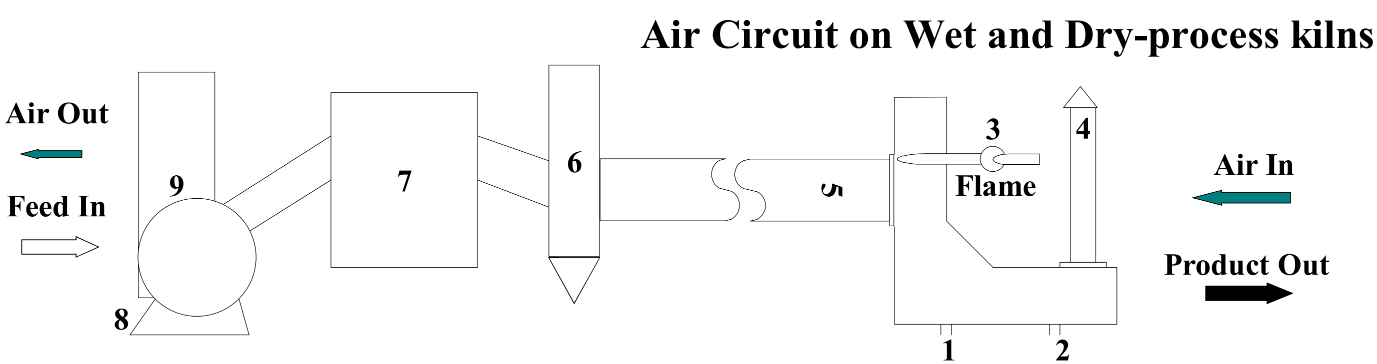
An Example of a kiln



1, 2 -- air inlets into the undergrate chamber of the RASC cooler
3 -- the primary air fans and burner
4 -- excess cooler-air stack
5 -- kiln
6, 7 -- dust collectors
8 -- induced draft fan
9 -- stack

Project Charter

- **Problem Statement**
  - Significant variations in secondary air temperature resulted in inefficient burning of the costly Bunker C fuel and poor heat recovery.
  - Average value of specific oil consumption, the critical process metric, and its variations were too high resulting in an unacceptable overall production cost.
  - Customers complained about inconsistent product quality as reflected in the bulk specific gravity, the critical customer quality metric.

- **Project Scope**
  - Project begins with the loading of washed ore to the kiln and ends with the calcined product being discharged from the folax cooler. Includes excess oxygen controls, kiln temperature control, and burning zone temperature control as well as heat recovery from the folax cooler.
  - Develop a new secondary air temperature optimization model and kiln performance ratios.
  - Build a Decision table to enhance operator control of changes in the kiln environment.
  - Train all operating shifts on use of model and table.

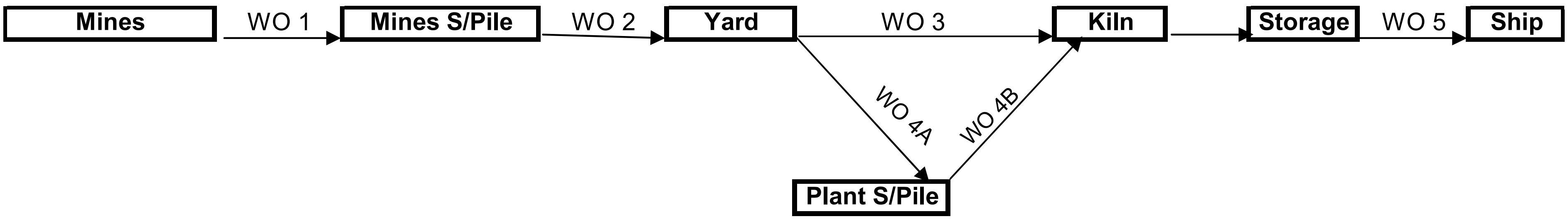
- **Goal Statement**
  - Control XO2 to the 1-2% range.
  - Build Advance Control Models and set-point charts for KS, BET, BZT, SAT, BT control.
  - Lower SPOC by 5%.
  - Maintain TPH at or above existing average.
  - Ensure newly defined processes maximize kiln's through-put.

- **Business Case/Benefits**
  - The optimized secondary air temperature and excess oxygen control processes will:
    - reduce SPOC by at least 5%, a savings in excess of $30,000 per month.
    - increase kiln thru-put.
    - reduce kiln temperatures and downtime due to mechanical failures.
  - Provide the operators with a standard operating model for all shifts thus minimizing product quality variations.
  - Knowledge gained from the new methods of operation can be applied to other kilns.

Team

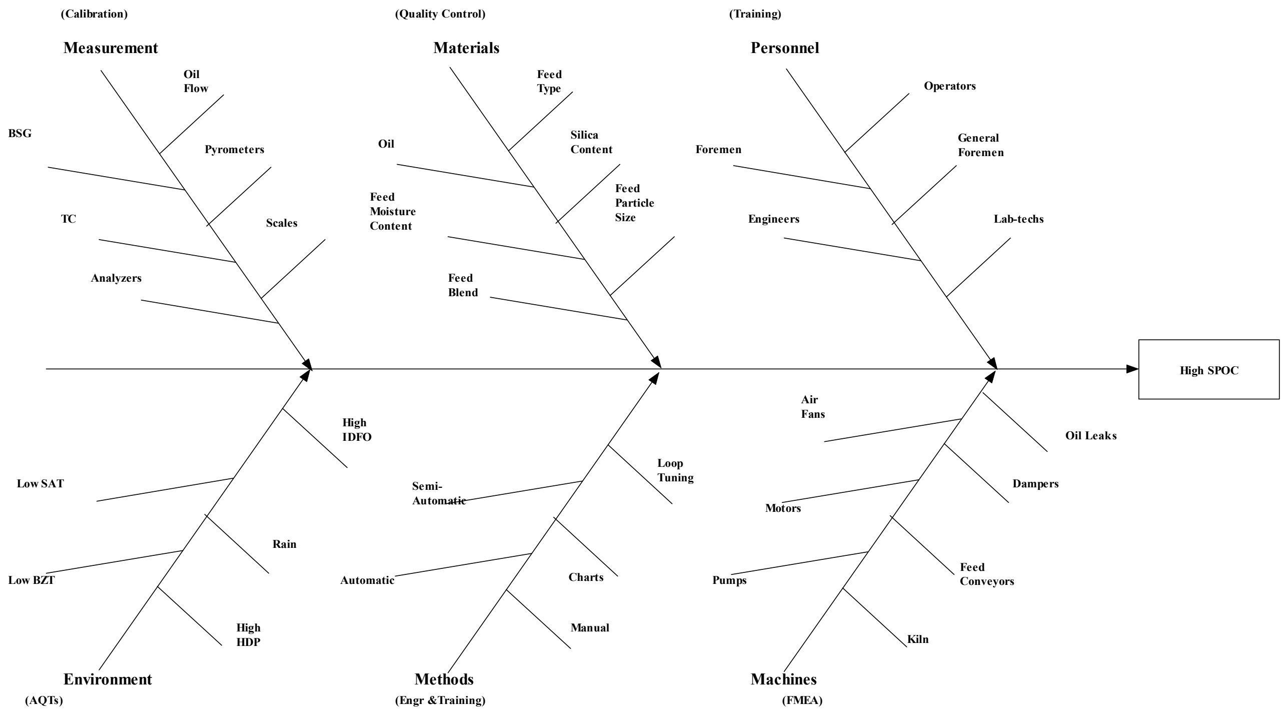
- **General Manager:** **Bob Walish**
- **Project Champion:** **Vic Rozon**
- **General Foremen:** **B. Hummer, R. Churchill**
- **Team Member:** **Foremen/Operators**
- **Project Consultant:** **Owen Ramsay**

Define Phase



Work Order	Acceptance Limits				
	Si (%)	Fe (%)	Ti (%)	BSG	Mesh
WO 1	≤ 15	≤2 (Visual &			
WO 2, WO 4A	≤15	≤2			
WO 3, WO 4B (input)	≤5.5	≤1.5			
WO 3, WO 4B (output)	≤6.5 (Indicativ	≤1.75		>3.0	(3 x 6)
WO 5	≤7.5	≤1.75	≤1.75	≥3.1	(-6 - 10)

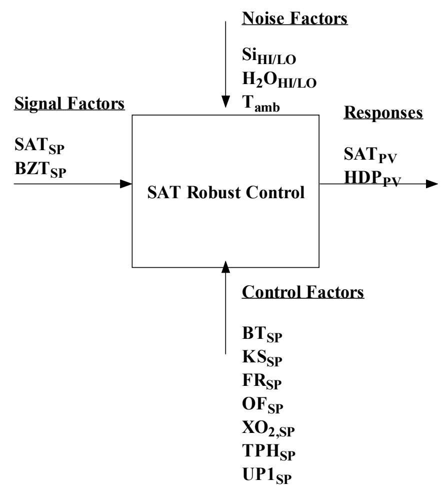
Define Phase



High SPOC Fishbone Diagram

Taguchi's P-Diagram

Taguchi's P-diagram



SAT -- Secondary Air Temperature
BZT -- Burning Zone Temperature
HDP -- Hood Draft Pressure
BT -- Folax Bed Thickness
Si -- Silica Content
IDFO -- Induce Fan Opening
KS -- Kiln Speed
FR -- Feed Rate
TPH -- Tons per hour of product
OF -- Oil Flow
HI/LO -- High Level / Low Level
PV -- Process Variable Level
SP -- Set-Point Level

Results of Define Phase

- Defined scope along with internal and external critical-to-quality metrics, cost-benefits, and team relationships;
- Results:
  - Descriptive statistics and Taguchi’s P-diagram used to identify key variables;
  - determined past trends and improvement targets;
  - performed a cost-benefit analysis;
  - established a responsibility and communication matrix.
- Tools: Descriptive statistics, Line plots, histograms, P-diagram

Measure Phase

- Goals:
  - Gather data and assess the current status
  - Use historical data to define linear relationships. Brainstorm potential relationships using a fishbone diagram and collect data to understand those relationships deemed significant.
- Results:
  - The important CTQs identified were SPOC, tonnage, BSG
  - Averages and variations of the CTQs were estimated and targets set.

Measure Phase

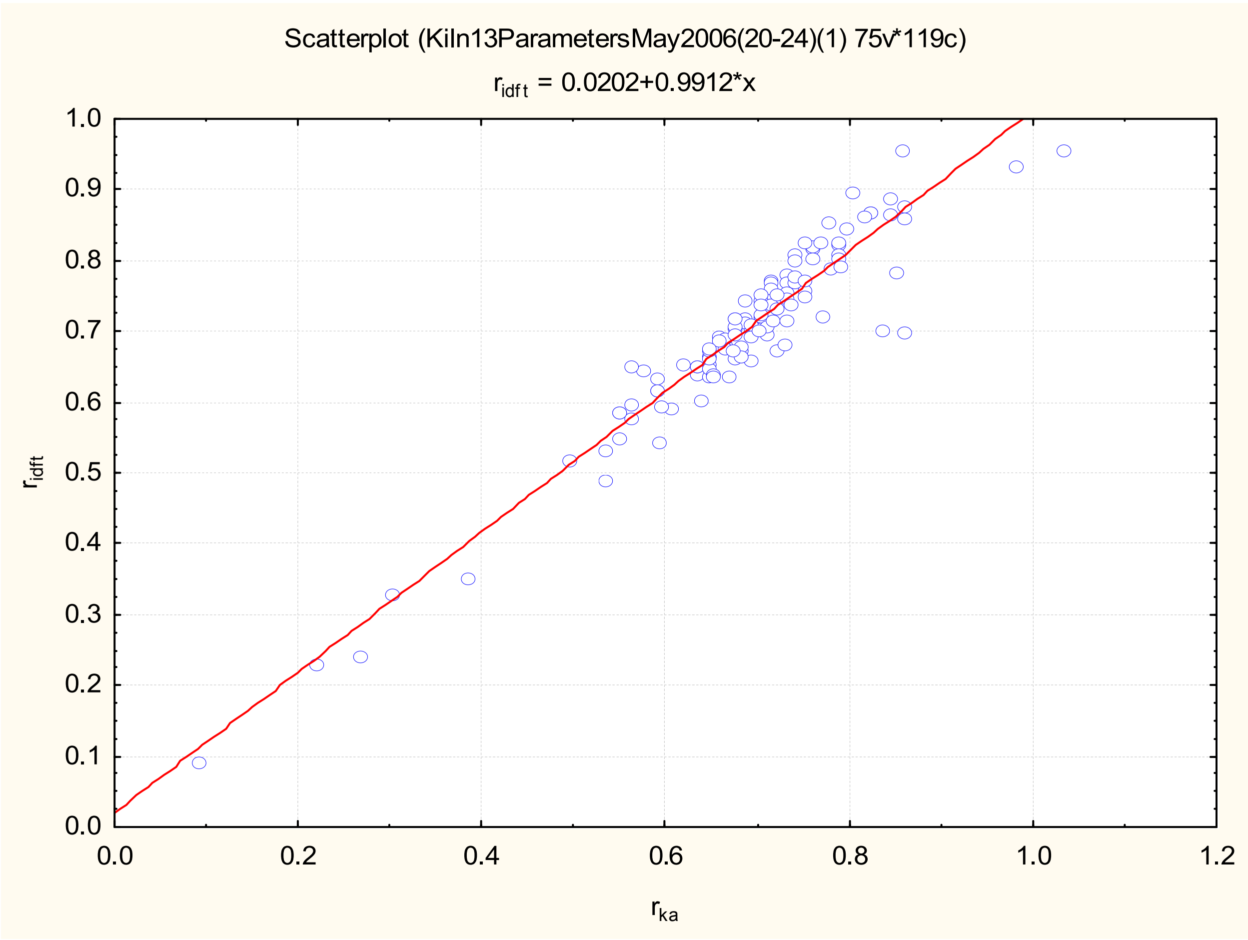
Project: Kiln Peformance Improvement

Level of Commitment	Management										
	Vic (GM)	Peter (S)	Ron (S)	Barry (GF)	Robert (GF)	Rob (GF)	Jean (GF)	Randy (GF)	Kevin (GF)	Rawle (F)	Sherwyn (AF)
Supporter	X O T	O	O	O	X O	X O	X O				
Compliant		X T	X					X O	O	O	X O
Indefferent								T	X		T
Uncooperative									T	X	
Opposed			T	T	T	T	T				
Hostile				X						T	
Not Needed											

Legend: X = present level of commitment
O = required commitment level
T = initial level of commitment

	Valid N	Mean	Median	Mode	Frequency of Mode	Minimum	Maximum	Lower Quartile	Upper Quartile	Range	Std.Dev.
BSG	342	3.136	3.140	3.130000	65	2.2500	3.260	3.110	3.180	1.010	0.0793
RPM	345	1.150	1.160	1.180000	63	1.0000	1.220	1.140	1.180	0.220	0.0500
Feed Rate	345	53.655	55.000	56.00000	80	15.0000	62.000	52.000	56.000	47.000	4.4702
GPM Oil	355	3673.214	3850.000	3875.000	99	662.0000	6034.000	3510.000	3875.000	5372.000	527.6614
Tons Per Hr.	343	21.385	21.000	21.00000	42	6.0000	126.000	19.000	24.000	120.000	7.4671
Flue Gas Temp	357	570.702	606.000	596.0000	8	5.3800	752.000	577.000	633.000	746.620	158.3629
Excess O^2 %	345	1.009	0.900	.9000000	43	0.1000	5.500	0.700	1.100	5.400	0.6726
SPOC	343	51.414	47.948	47.94823	16	0.0000	175.810	41.662	54.444	175.810	20.6080
B/Zone Temp.	341	2803.543	2807.000	Multiple	6	280.0000	3599.000	2764.000	2870.000	3319.000	189.1622
$SPOC^{EFF}$	361	48.850	47.639	0.000000	22	0.0000	175.810	40.624	53.083	175.810	23.0007
Silica Product	334	5.460	5.400	5.000000	33	3.1800	8.110	5.000	5.800	4.930	0.6810
Sec. Air temp	344	1370.977	1393.000	Multiple	5	64.0000	2987.000	1309.500	1458.500	2923.000	248.4035
Bed Thickness	341	10.825	10.620	Multiple	11	0.8000	38.310	9.660	11.900	37.510	2.3876
Hood Draft	332	-0.099	-0.080	-.0100000	53	-0.7500	0.260	-0.160	-0.030	1.010	0.0938

Analyze Phase -- Scatterplot



Analyze -- Set-Point Matrix

FR	KS	BET	BZT	SPOC	SAT	BT	UP1	UP2	UP3	UP4
50	1.19	590	2724	34.73	884	10.48	13.27	12.26	12.26	11.21
51	1.21	599	2740	36.76	908	10.90	13.59	12.50	12.38	11.36
52	1.22	607	2765	36.40	913	10.96	13.68	12.62	12.50	11.50
53	1.26	623	2850	38.24	944	11.34	14.13	13.00	12.87	11.82
54	1.27	630	2871	37.80	948	11.38	14.21	13.11	12.98	11.95

Analyze -- FMEA

Date	Item and Function	Start of failure	End of failure	Duration of failure	Potential failure mode	Effects of failure	Cost of failure	Sev	Possible causes of failure	Occ	Current Prevention Methods	Current detection methods	Det	RPN	Recomm. Action	Who? And Target date	Action taken	Sev	Occ	Det	RPN
	Excess Oxygen Control Loop																				
	Kiln Speed Control Loop																				
	Feed Rate Control Loop																				
	Secondary Air Control Loop																				
	Hood Draft Press. Control Loop																				
	Folax Bed Thickness Control Loop																				
	Folax Compartment #1 Control Loop																				
	Folax Compartment #2 Control Loop																				
	Folax Compartment #3 Control Loop																				
	Folax Compartment #4 Control Loop																				

CONROL FUNCTION	PRIMARY VARIABL	SECONDA VARIABL	CONTROL VARIABL	ARIMA (p,d,q)	ARIMA MODEL	CONTROL EQUATION
EXCESS OXYGEN	XO2		IDFO		$x_t = -3.8068\,(-0.005\Delta GPH - 0.0361\Delta FR$ $-1.9152\Delta KS + 0.1145\Delta HDP + \Delta XO2)$	
		FR		1,0,0	$p_1 = 0.804$	
		OF		3,0,0	$p_1 = .123,\ p_2 = .205,$ $p_3 = .188$	
		HDP		3,0,0	$p_1 = .651,\ p_2 = -.087$ $p_3 = .21$	
BACK-END TEMP.	BET		OF	3,0,0	$p_1 = .123,\ p_2 = .205,$ $p_3 = .188$	
		KS		1,0,0	$p_1 = .7$	
		FR		1,0,0	$p_1 = .804$	
		BZT		1,0,0	$p_1 = .744$	
SECONDARY AIR TEMP.	SAT		BT	0,0,0	μ (no ARIMA)	$x_t = 0.00129412\Delta\, bzt - 0.00224235\, b\Delta\, bzt +$ $-5.13435\,\Delta ks + 4.81921\, b\,\Delta ks$
		BZT		1,0,0	$p_1 = .744$	
		KS		1,0,0	$p_1 = .7$	
FOLAX BED THICKNESS	BT		GS	1,0,0	$p_1 = .385$	$x_t = -(0.4461 b\Delta GS + 0.2423\, b^2\Delta GS$ $-11.3233\, b\Delta KS - 6.5352\, b^2\Delta KS$ $-0.7423\, b\Delta BT - 0.5265\, b^2\Delta BT)$
		KS		1,0,0	$p_1 = .7$	
KILN SPEED	KS-FR-R	NONE	FR	N/A	REGRESSION MODELS ARE TO BE USED TO DEFINE RATIOS	
			KS	N/A		

Analyze Phase

- Goals:
  - Identify factors and causes that determine the CTQ behavior.
  - Generate operator friendly solutions that results in an optimized process.
- Results:
  - Variables were transformed and correlated with $r^2 > 0.8$ as target.
  - Multiple linear regression and Box-Jenkins transfer function models applied to understand system dynamics and disturbances.
  - Set point matrix for process control loops.
- Tools Used: Multi-linear regression, Box-Jenkins Time Seires, X-Bar & R charts, t-test, ANOVA, FMEA

Improve Phase

- **Goals:**
  - Determine the set-point matrix for control loops
  - Design and implement modifications to the process to improve performance.
  - Quantify the gains made.
  - Create a Decision Table that will improve the response of operators to adverse conditions.
  - Train operators to the new documented procedures.

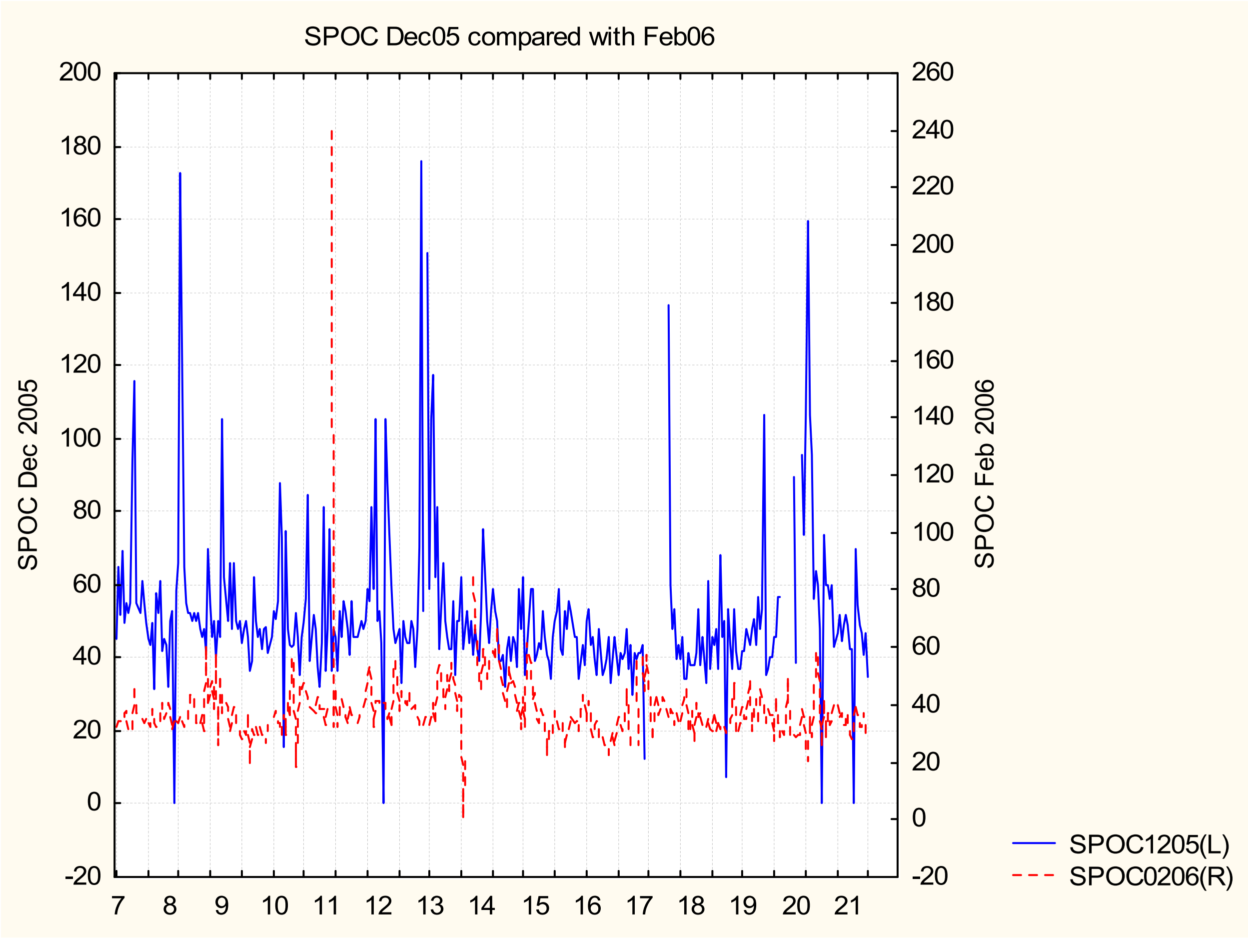
- **Results:**
  - The operators applied the set point matrix values to the control loops over a test period of 72 hours. The results were impressive.
  - The Decision Table helped achieve consistency of operation from shift to shift.
  - Models were built for the other kiln in operation with similar results.
  - The savings per kiln was significant.

- **Tools Used:** Multi-linear regression, Design of Experiments, Standardization, Response Surface Methodology, t-test, ANOVA.

Improve Phase (cont'd)

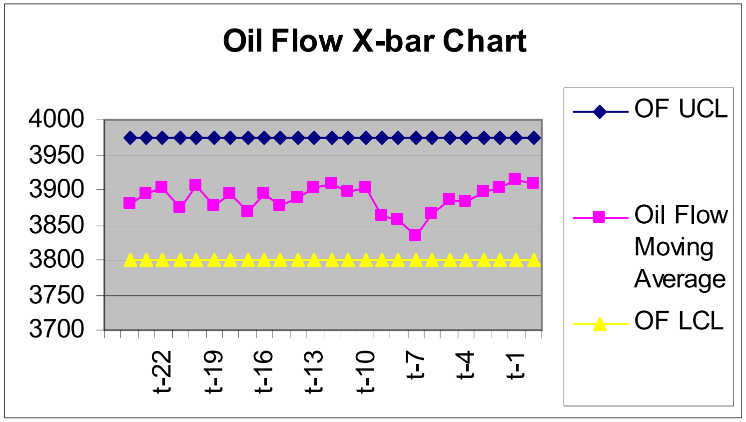
		Rule #1	Rule #2	Rule #3	Rule #4	Rule #5	Rule #6	Rule #7	Rule #8	Rule #9	Rule #10	Rule #11	Rule #12
Conditions													
Environment	Rain												
Feed Chracteristics													
	Fine												
Feed	Very Wet												
	Off-grade												
	High												
Silica	Normal												
	Low												
Process													
	High												
BET	Normal												
	Low												
	High												
MKT	Normal												
	Low												
	High												
BZT	Normal												
	Low												
	High												
XO2	Normal												
	Low												
Product													
	High												
BSG	Normal												
	Low												
	High												
TPH	Normal												
	Low												
Actions													
KS	INCR												
	DECR												
FR	INCR												
	DECR												
OF	INCR												
	DECR												
IDFO	INCR												
	DECR												
GS	INCR												
	DECR												
FO1	INCR												
	DECR												

Variables	Dec-05	Feb-06	Mar-06	%Change
SPOC	50.117	38.6	35.8	-28.57
Through-put	21.9	25.4	26.9	22.83
Oil flow (kg/hr)	3834.8	3481.7	3482.9	-9.18

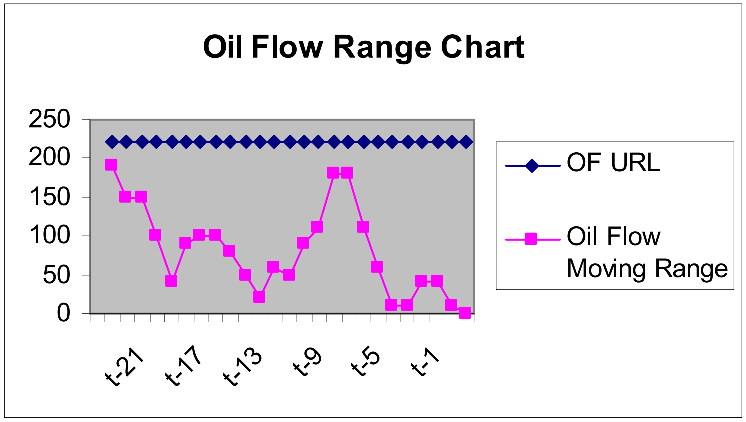

SPOC Dec05 compared with Feb06
SPOC Dec 2005
SPOC Feb 2006
200
180
160
140
120
100
80
60
40
20
0
-20
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
SPOC1205(L)
SPOC0206(R)

Control Phase

- **Goal:**
  - For the operators to make statistically valid decisions by knowing when and when not to take action on the process thus ensuring continued improved performance.



- **Results:**
  - Operations personnel were trained on how to use off-line Excel based SPC charts that were built to prevent over-control and the concomitant process instability.



Executive Summary

- What was the problem?
  - An inefficient and uncontrollable process. .
  - Customers complained about inconsistent product quality
- What did we do?
  - Determined the set-point matrix for control loops that minimized variations in CTQs,
  - Created a Decision Table that helped reduce the shift-to-shift variations between operators' response to adverse conditions.
  - Trained operators to the new documented procedures.
- What were the benefits?
  - Reduced internal CTQ by more than 25%, resulting in savings in excess of $150,000 per month.
  - Increased the production rate by more than 20%.
  - Reduced operating temperatures and downtime due to mechanical failures by more than 70%.
  - Provided the operators with a standard operating model for all shifts thus minimizing product quality variations.
  - Knowledge gained from the new methods of operation was applied to the other kiln.