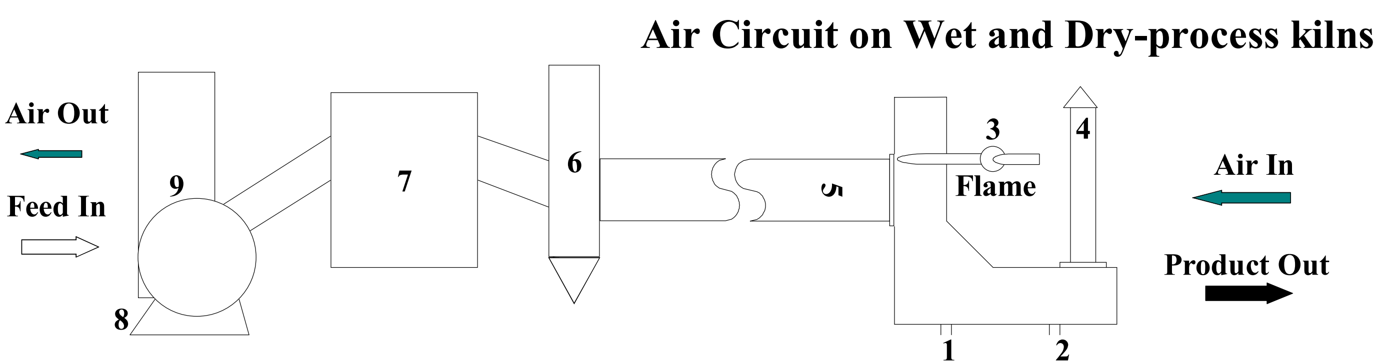
# Process, Quality and Efficiency Enhancements using LSS

Owen Ramsay, BSChE, MSEE, CQE, CQM, CSSBB

# 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.

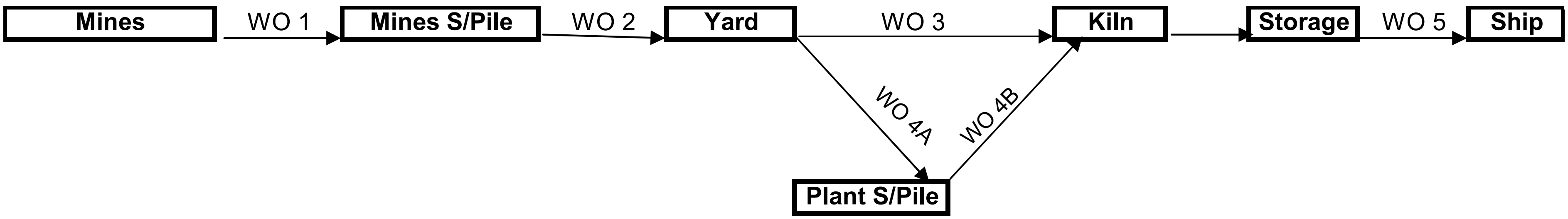
- **Goal Statement**
  - Control XO2 to the 1-2% range.
  - Build Advance Control Models and set-point charts for KS, BET, BZT, SAT, BT control.
  - Lower SPOC by 5%.
  - Maintain TPH at or above existing average.
  - Ensure newly defined processes maximize kiln's through-put.

- **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

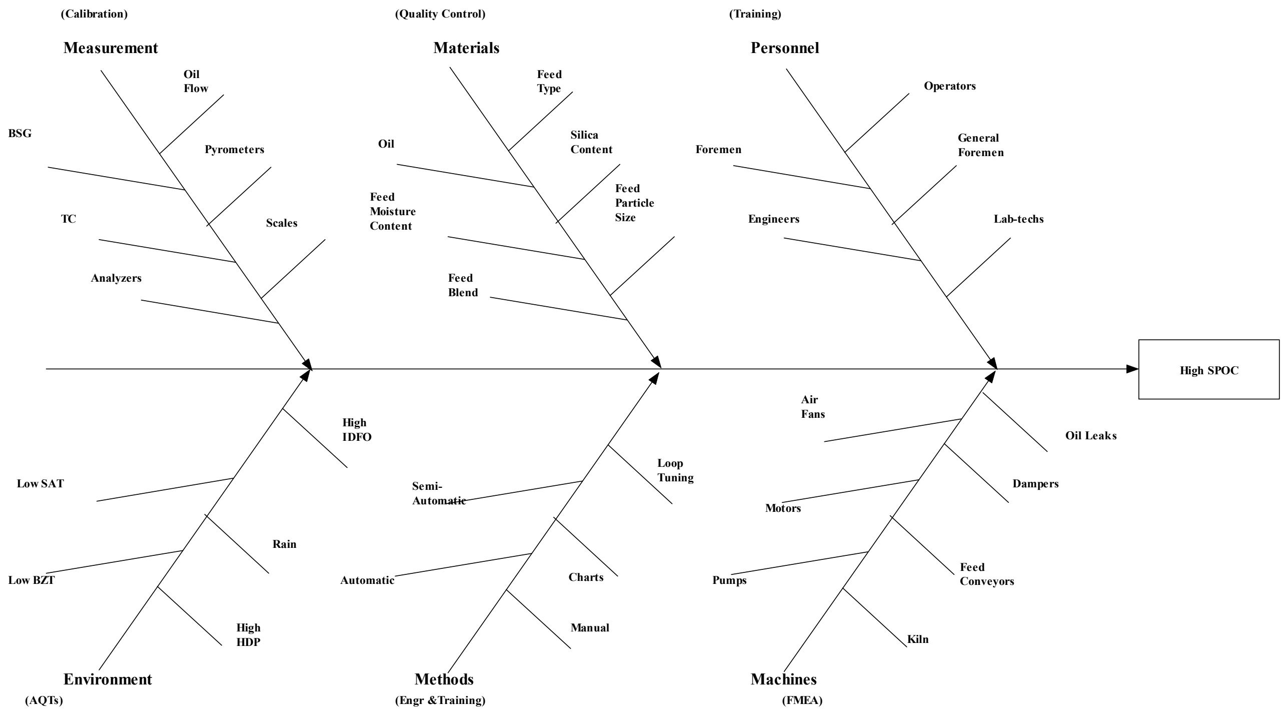
- **General Manager:** **Bob Walish**
- **Project Champion:** **Vic Rozon**
- **General Foremen:** **B. Hummer, R. Churchill**
- **Team Member:** **Foremen/Operators**
- **Project Consultant:** **Owen Ramsay**

# 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) |

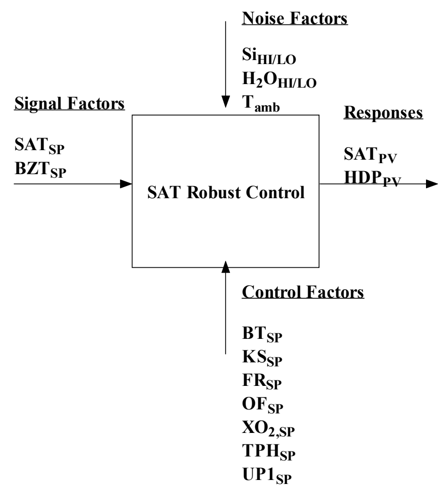
# Define Phase




**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

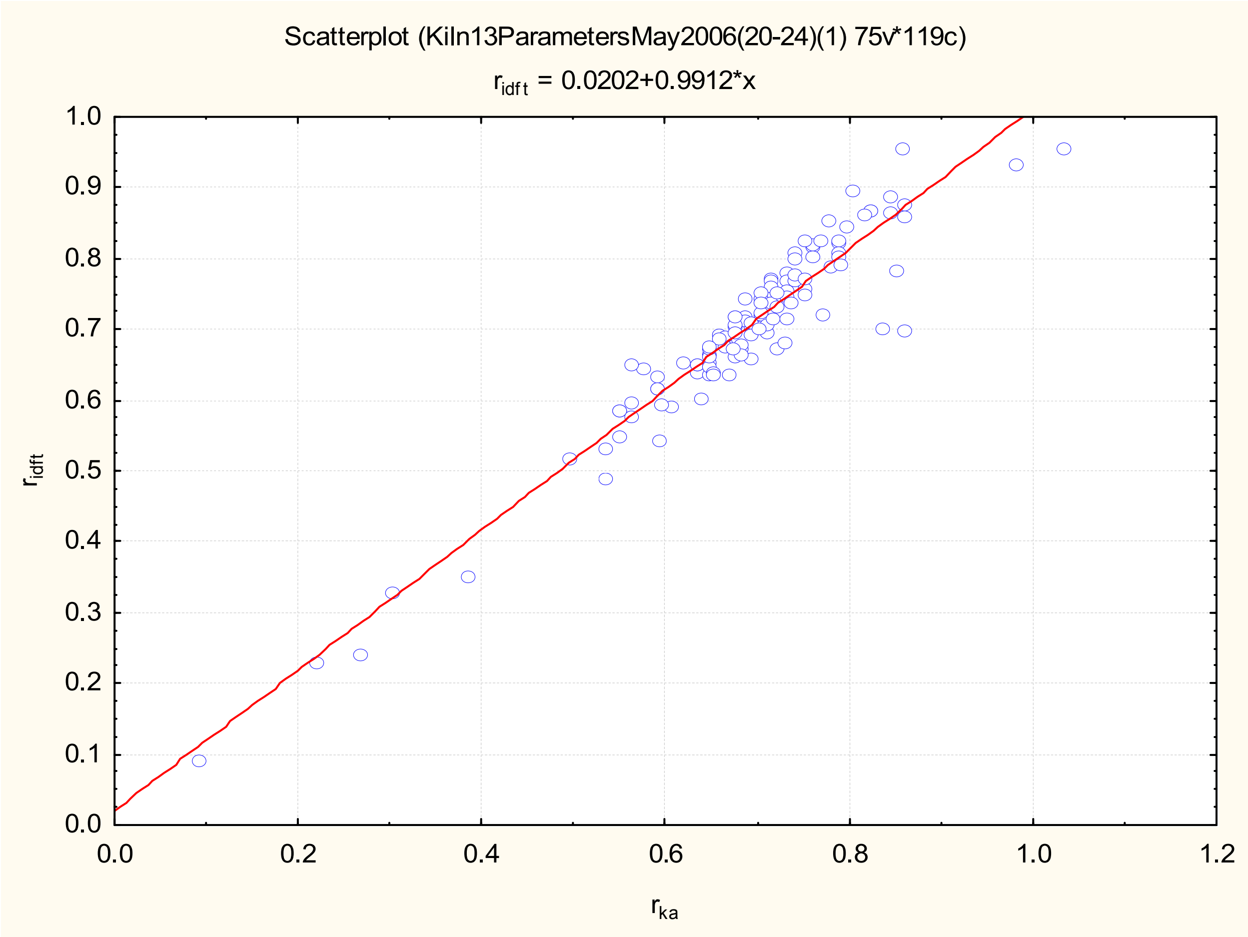
**Project: Kiln Peformance Improvement**

| 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 | $p_1 = .385$ | $x_t = -( 0.4461b\Delta GS + 0.2423\ b^2\Delta GS -11.3233\ b\Delta KS - 6.5352\ b^2\Delta KS -0.7423\ b\Delta BT -0.5265\ b^2\Delta BT)$ |
| | | 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.

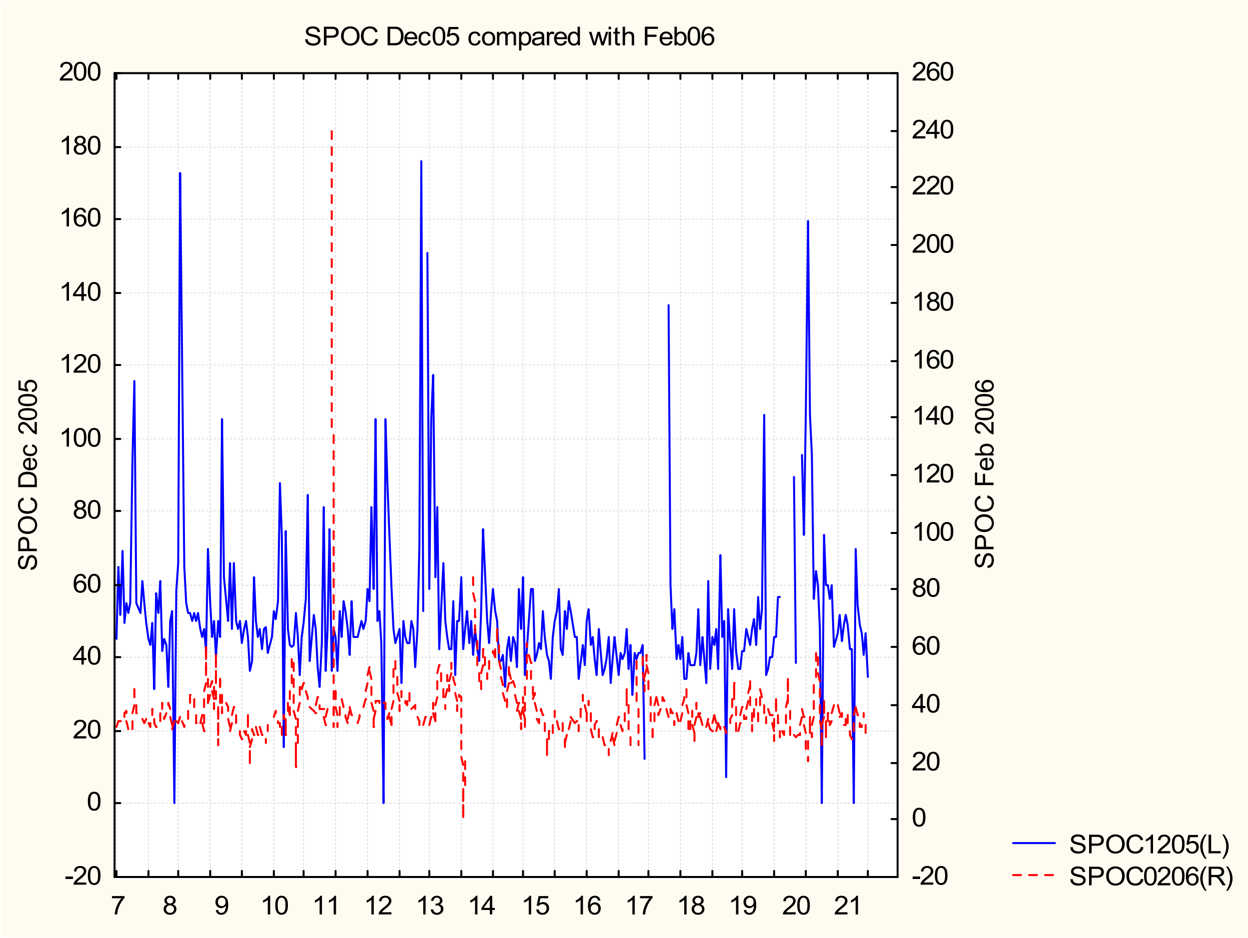
- **Results:**
  - The operators applied the set point matrix values to the control loops over a test period of 72 hours. The results were impressive.
  - The Decision Table helped achieve consistency of operation from shift to shift.
  - Models were built for the other kiln in operation with similar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

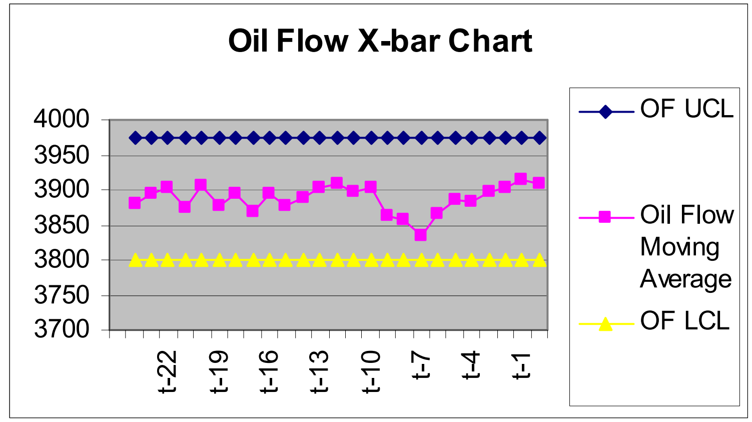
| | | Rule #1 | Rule #2 | Rule #3 | Rule #4 | Rule #5 | Rule #6 | Rule #7 | Rule #8 | Rule #9 | Rule #10 | Rule #11 | Rule #12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Conditions** | | | | | | | | | | | | | |
| **Environment** | Rain | | | | | | | | | | | | |
| **Feed Chracteristics** | | | | | | | | | | | | | |
| | 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 |

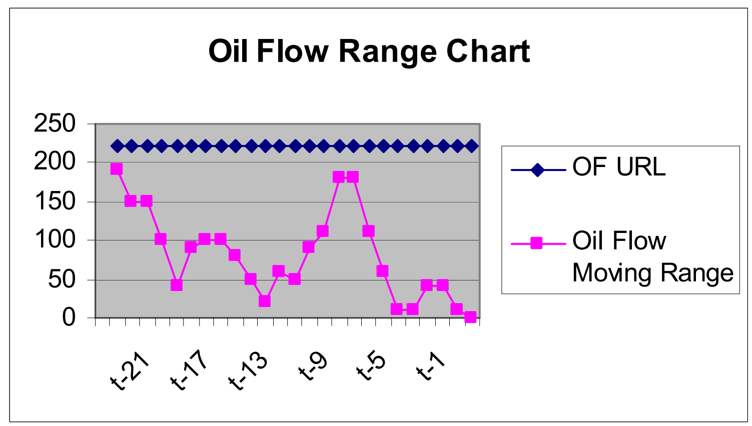

SPOC Dec05 compared with Feb06
SPOC Dec 2005
SPOC Feb 2006
200
180
160
140
120
100
80
60
40
20
0
-20
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SPOC1205(L)
SPOC0206(R)

# 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.