Automation to Improve Quality Control

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Abstract

The Cementos Progreso Plant, located in San Miguel, Guatemala gradually grew from a single line installation to the complex 3 line plant it is today. With the plant growth, the quality control and quality assurance demands also grew in both number and complexity. Currently, the plant is operating the three lines, fueled 100% by high sulphur petcoke (up to 6.5%) in its kilns. Clinker production is enhanced by mineralization, the addition of fluorine to change the clinkering dynamics. The plant produces a low clinker factor GU cement (60%) a puzzolanic type P cement among others. A lime (CaO) plant is also sharing resources for its quality control, and use of alternative fuels also demands a high degree of product uniformity.

This paper reviews the evolution of quality control solutions at the San Miguel Plant, focusing on the most recent automation efforts that involved 20 plant sampling stations, a robotic laboratory cell and advanced chemical control. The benefits and challenges are both discussed.

Introduction

Cementos Progreso S.A. was founded in 1899 by Carlos F. Novella. The plant produced, what was then impressive, more than 100 bags of cement per day, in Finca La Pedrera, a suburb of the developing Guatemala City. The "La Pedrera" facility grew quickly, first a production increase of 500 bags/day to a peak of 22,000 bags/d in 1915, with 2 long dry kilns and 4 small balls mills.

In 1971 a plant was started at San Miguel, located 46 km northeast from Guatemala City in El Progreso department. The first kiln was a 3 support kiln that featured a 4 stage preheater and satellite cooler. This plant produced 800 tpd production of clinker. In 1980, a second line of production was commissioned, a similar size kiln with a higher output of 1600 tpd clinker. During 1992, the production of both kilns was boosted by 20% giving the plant a total of 3000 tpd clinker. Cement grinding was done by 2 ball mills and later with the later addition of a roll press.

As the only cement producer in the country, Cementos Progreso decided to add a third line to the San Miguel facility. The third line included all of the state of the art features for cement production available at that time.

A new 1100 tph primary crusher was installed that fed to a prehomogenization building housing 2 x 20,000 ton piles. The pile composition was measured by a PGNAA analyzer with manual composition adjustments. A new 230 tph vertical raw mill was installed to support a new kiln, that had a capacity of 3000 tpd of clinker. The pyro line featured a 5 stage linear precalciner and a new style grate cooler.

Two 20 tph fuel mills were added to provide coal for all 3 lines. (These now process the petcoke for all 3 lines.)

New technology for cement grinding was employed. A vertical roller mill was installed for cement grinding, which was a the first installation of its kind in the Americas. The success of the first mill, commissioned in 1998, led to the installation of a second, commissioned in 2000. The mills have a combined capacity of 280 tph of cement – a striking contrast to the 100 bags per day capacity from 100 years earlier.

Product dispatch was supported by a bank of automated packers that featured an initial capacity of 2000 tph and was quickly expanded to an automatic palletizing system of 3000 tph.

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History of Quality Control

With the completion of Line 1 in 1976, a typical manual laboratory analysis was commissioned to support the quality control efforts. All samples were manually collected, transported, prepared and analyzed. Manual calculations process this data and combined with experienced intuition, formed the basis for raw mix control.

The addition of a second line put a strain on the manual system. The system was enhanced by the addition of a sampling/transport system for a raw mill sample in 1984 and the addition of an xray spectrometer shortly after.

The addition of the third line further strained the capabilities of a primarily manual system. Further enhancements including additional sampling equipment and a more capable xray spectrometer and diffractometer.

Despite these enhancements, the sample quantity exceeded a reasonable threshold for the labor intensive system, despite the semi-automatic sampling systems that were in place. Quarry variations and weaknesses in repeatability in the sampling and preparation procedure resulted in significant instability in the quality control (standard deviation of the kiln feed LSF of 12 % for example). This instability was adversely affecting the plant stability and resultant product quality.

Laboratory Automation Project - Objectives

After some preliminary investigations, a laboratory upgrade project was approved in 2003. The project team was charged with the task of improving quality control and specifically product quality across the plant. After considerable study, following objectives were outlined for the project:

- Provide an automatic system to sample and analyze raw mix, clinker and cement, and take appropriate control action on a 24 hour basis, 7 days per week.
- Improve the quality of the prehomogenization pile by upgrading the control software using data from the existing cross belt analyzer
- Improve the sample quality – including reproducibility, schedule and time synchronizations
- Re-define sampling locations to maximize process control and not sampling convenience
- Reduce all components of analytical error for all samples. This includes sample collection, sample contamination, sample identification, sample preparation and sample analysis.
- Reduce the internal errors recording and transmitting sample analysis results and proposed corrective actions.
- Shift staff focus from sample processing activities to data analysis and process improvement.
- It is important to note that manpower savings was not the basis for the project. The cost/benefit equation was driven primarily by quality improvements and the major cost benefit those can have on the entire process.

A Phased Approach

The ambitious objectives of the project were to translate into a fairly complex solution, including many detailed subsystems to handle sampling, sample transport, sample preparation, analysis, data collection, and process control. In addition, the laboratory staff, while dedicated and competent with the existing systems, would have a significant learning curve to absorb and master the new technology. For this reason, as well as for budgetary considerations, the project was divided into 3 phases:

- Sampling and Sample Transport using existing preparation techniques
- Computer control based on this data
- Robotic cell for automated preparation and analysis.

The project extended from December of 2005 until August of 2007, a little more than 1.5 years.

<u>Phase 1 - Sampling – Where and Why</u>

The quality control and quality assurance of three production lines and a nearby Lime Plant require as many samples taken on a controlled and reproducible schedule. In order to accomplish this, a pneumatic post sample transport system was installed. The samples handled by this system included (in process flow order):

1) Quarry Sample – At the discharge of the primary crusher, a manual sample crusher and manually loaded transport station was installed. This sample primarily provides a check on the pre-homo pile composition which is controlled by analyses received from an existing PGNAA analyzer. The extreme distance, approaching 0.5 km, and large vertical drop required special design considerations.

2) Raw Mills – Control of the chemistry of the feed is a key objective of the system. The plant has two ball mills and one vertical mill producing raw material. Each mill is sampled by a classical screw/mixer arrangement. The sample screw is installed into the material flow and operates intermittently to generate a composite sample in the nearby mixer. At the scheduled time, the mixer is emptied and a sample of this material is collected discharged into an automatic plant station, where it is sealed in a plastic capsule and transported to the laboratory. Each of the mills was supplied with a sampler, mixer and transport station. In line with classical Progreso philosophy, the latest control technology is employed. The stations and related motors and controls are fully networked. This simplifies detailed trouble shooting, which can be done from the laboratory, from the control room, or from a continent away.

3) Kiln Feed Samples – Ideally, tight control on the raw mix chemistry and smooth homogenization by the blender should make kiln feed sampling unnecessary. Those who have spent considerable time in a cement plant have come to learn that “ideally” and “actually” often differ and the decision was made to collect kiln feed samples prior to entry into the preheater tower. This sample, while primarily a check sample, is used to warn of potential kiln feed chemistry problems and enables the kiln burners to shift the process to a more “defensive position”. A screw sampler and mixer was installed for each of the three kilns. A transport station was also supplied for Kilns 2 & 3, while the samples for Kiln 1 could be transported by a nearby station.

4) Hot Meal Sampling – Three hot meal sample systems were installed, one for each kiln. The sampler consists of a piston operated sample designed to survive the extreme conditions of the material leaving the calciners. The sample is extracted and cooled in a water cooled heat exchanger prior to transport. The plant operating personnel have found this sample to be extremely important in controlling and stabilizing the kiln. The automatic system eliminates the risk involved with manual collection of this sample.

5) Clinker Sampling – Three clinker samplers were also installed. The samplers installed were single stage models, where a sample is collected, the over and undersize is removed and transported to a mortar mill that is mounted above the sample transport station. The single stage approach potentially provides a less representative sample than a two stage version (where crushing, splitting, and grinding provides a dual split), however has the benefit of significantly less complexity, cost and maintenance. At the time of this writing, one clinker sample is automatically transported to the laboratory, while the remaining two are automatically collected and manually transported, waiting for enhancements to the transport system.

6) Cement Sampling – 4 cement mills, two ball mills and two vertical mills are routinely sampled. The samples are collected in two ways – two mills are sampled via a classical screw/vertical chute configuration and two are sampled with airslide samplers. In the latter, a vertical tube in mounted in the airslide material flow and rotates to collect a sample at programmed intervals. All of the samplers discharged into mixing tanks where composite samples are developed. Three automation transport stations are provided – samples from the two airslide samplers are in close proximity and share a common station.

7) Product Dispatch – The cement leaves the plant from a fairly complex dispatch facility. Bags and Bulk product are supplied in various forms. In order to efficiently and economically sample and monitor the various product shipments, a manually loaded transport station was installed in the dispatch area where a sample is logged and transported to the laboratory for automatic analysis and possible storage.

8) Lime Plant – Progreso operates a Lime (CaO) plant that is located adjacent to the cement plant. A manually loaded transport station conveniently located enables the operator to quickly transport samples to the main laboratory for analysis and storage.

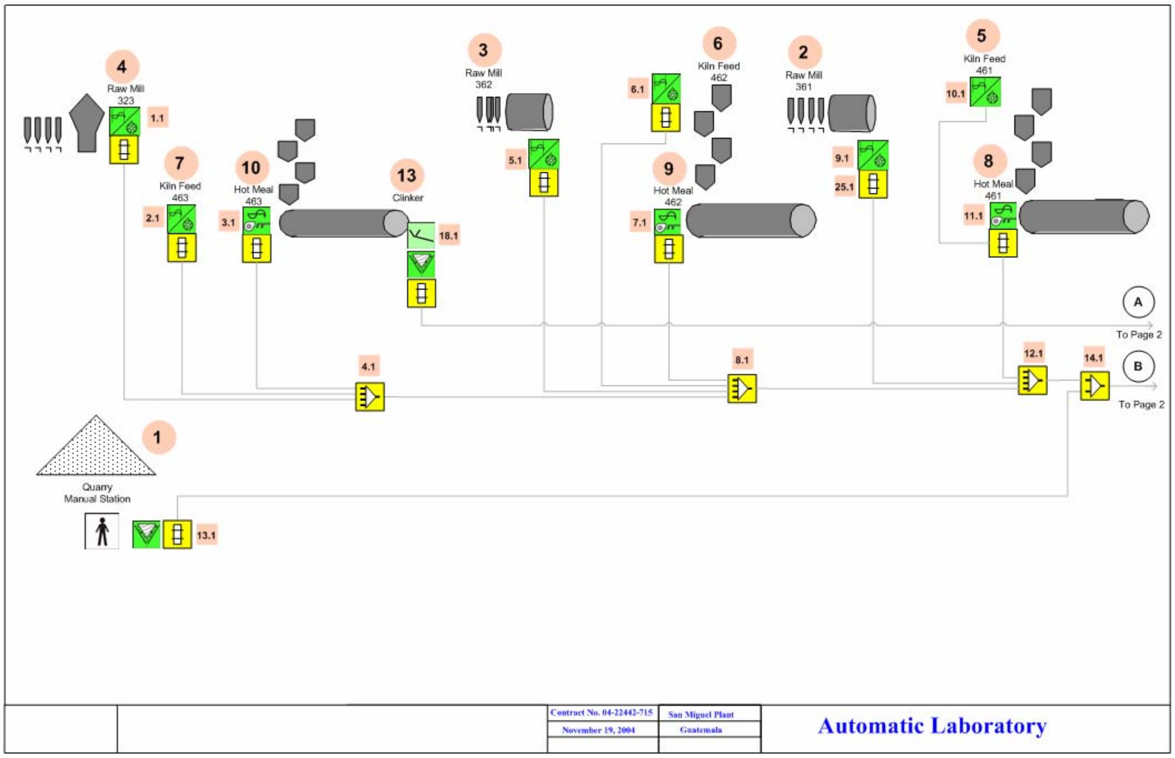
9) Fuel – Petro Coke is a major fuel for the plant and since it is a by-product, the composition and combustion characteristics can vary considerably. While automatic sampling and analysis of combustible materials is technically possible, the safety and cross contamination considerations make it costly. A manually loaded transport station, conveniently located in the fuels area was selected as an economic compromise. These samples are directed to a manual receiving station in the laboratory for manual processing.

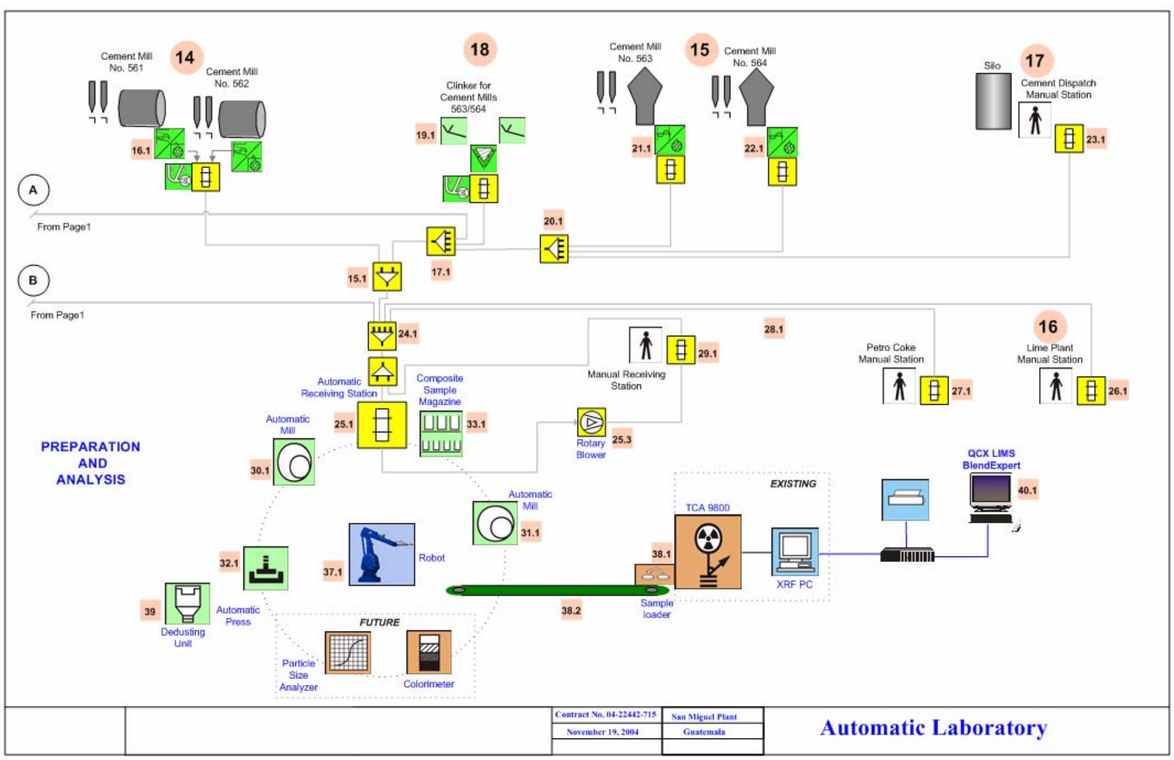
10) Sample Reception in Laboratory – As outlined above, the sample transport system collects samples from 21 locations throughout the site and transports them to one of two stations in the laboratory:

    a. Manual Station – Samples from the Lime Plant, Cement Dispatch, Quarry and Fuel are automatically diverted to the manual station, located in the laboratory, outside of the robot cell. This allows manual processing of these samples. This station is also used for special samples or for sample processing while automatic station is down for maintenance – providing a smooth transition to manual backup.

    b. Automatic Station – The automatic laboratory station processes the bulk of the samples. The sample capsule is received, emptied, cleaned and returned to the sending station. The station is equipped with a flexible dosing mechanism that is capable of supplying sub-samples of various sizes for subsequent analyses or storage. Sample quantity for each subsample is checked by an integral electronic balance.

The overall configuration of the sampling/transport system, including the robot cell is shown in the following figures:





Phase 2 – Control

A key goal for the laboratory automation project was improved control. Phase 2 focused on the three key control targets – the raw mix for the three raw mills. The control algorithm mixes up to 4 components together in order to obtain a mix with the desired chemical characteristics. Lime Saturation Factor (LSF) is the key control parameter with Silica Modulus and Alumina Modulus added to support additional components. Using an internal process model for feedback, algorithm supports advanced targeting – linear methods to provide the "best possible" mix and utilized several different back-calculation techniques to better estimate the composition of the raw material components.

The pile control, for logistical reasons, was completed early in Phase 3. Analyses from an existing PGNAA analyzer were tapped and directed to pile blending software. The control software builds a "mathematical pile" that corresponds to the physical pile of the linear reclaimer. This model is used as a basis for pile corrections, quarry manager alarms, and anticipated reclaim composition.

Phase 3 – Robotic Cell

With the sampling and control in place, the remaining task was the robotic preparation cell, designed primarily to prepare samples for an existing xray spectrometer. The cell consists of a standard industrial robot that moves and coordinates samples between:

1. The laboratory automatic sample receiving station.
2. The sample check scale
3. The sample cup cleaning device
4. The sample grinding mills (2 are included to support sample load)
5. The sample press
6. The sample I/O and storage rack
7. The conveyors to and from the x-ray spectrometer

The cell is controlled by a fairly elaborate control algorithm that provides the control and flexibility required for a production laboratory. These include:

1. Sample Identification – A sample is identified the moment it is collected. The sample type determines the sequence of steps to be carried out in the robotic cell.
2. Parallel sample handling – Samples are scheduled on the basis of process priority, control samples have the highest priority.
3. Sub-sample processing – An incoming sample can be divided into several aliquots for multiple processing – these include xrf, composite, and sub-sample output for further manual tests.
4. Flexible composite sampling
5. Bulk processing of samples (i.e. from quarry drilling) on an "when you have time" basis.

The robot cell and laboratory transport station is supported by standard utilities including air, water, and an elaborate dust collection system.

Challenges

The laboratory project presented a number of technological and personnel challenges that were identified and addressed. The justification for the project was improved quality control and quality assurance – not the reduction of manpower. Recognizing this, Cementos Progreso was diligent in involving the laboratory engineers and technicians in all aspects of the project, and provided the training required to enable them to transition from a manual, labor intensive laboratory, to an automatic environment where sophisticated equipment needs the proper care and maintenance in order to function reliably. In addition, a culture shift was required to focus less on physically processing the samples and more on interpreting the results and detecting developing problems at an early stage.

In addition, the following specific challenges were encountered and resolved:

1. Where to put 3 km of steel transport tubing – Finding space and clear routings for the transport tube lines in a well established plant was a significant challenge. Fortunately, major runs could be located in electrical tunnels, which greatly simplified the routing and reduced the cost of installation.

2. The number of stations – The sheer number of plant stations, 20 automatic and manual combined, created a significant commissioning effort. In order to expedite the process and reduce cost, the stations were commissioned primarily by plant personnel. This enabled them to become active participants in the project and, knowing they had a vested interest in the outcome, were thorough in their efforts.

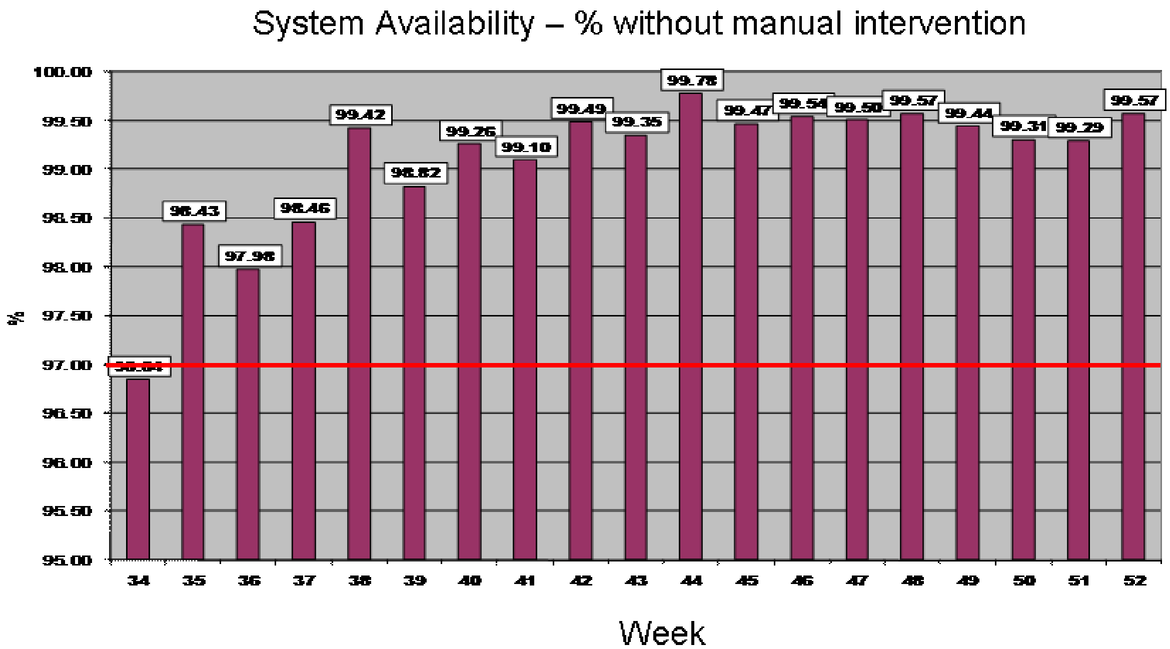
3. The plant-side commissioning was not without challenges. Misalignments and incorrect adjustments during the commissioning process often resulted in dust flying throughout the plant station, particularly the electronics, and improper sample timing resulted in material spillage in the stations. A dedicated effort was required to clean the stations after any mishap and correct the conditions that caused it.

4. The installation of the tubing presented its own set of challenges. In order to function efficiently, the 3+ kilometer tubing network had to be air tight and mechanically aligned. Early system tests exposed problem areas by loss of transport air and/or accelerated wear of the transport capsules. As with the plant stations, careful attention to detail and correction of all problems encountered resolved these issues.

<u>Results</u>

The first question everyone asks when viewing the finished installation is “does all this stuff work?” and when given an affirmative answer the second question quickly follows “how many specialists and how much work is required to keep in in operation ? “ The availability is a key performance indicator of the automatic laboratory installation. A low availability is indicative of design or maintenance problems which make it unlikely that other important objectives of the laboratory will be achieved.

The availability of the laboratory is defined on a results basis: the number of samples completed automatically divided by the number of samples required. Typical weekly values are shown in the figure below. While 100% availability is everyone’s goal, “things happen” and values above 97% are considered acceptable. The results shown below indicate a high availability.



In order to achieve and maintain this high level of availability, the machines are only part of the equation. Trained laboratory personnel, dedicated to the success of their mission are a key ingredient. Their duties include:

- Routine Cleaning and Check of Equipment – 30 minutes each morning
- Inspection and correction of all minor problems
- Review and analysis of analytical results
- Manage manual samples
- Perform Manual Analyses – Robot provides samples

While the availability of the automatic equipment is a good indicator of the overall health of the system, the main objective of the laboratory is to provide a high level of quality control. Simply running in automatic does not necessarily fulfill this goal. During the commissioning of the project, considerable testing was done to check out the performance of each part of the system as well as to demonstrate the benefits the laboratory investment achieved.

Sampling System – A number of tests, both formal and informal, were conducted to verify that a “good” sample was collected and transported into the laboratory. Given the large number of sample locations, rigorous testing would require a great deal of effort. Therefore, relatively simple tests were done with more detailed testing reserved in case process control or analytical results called the sample validity into question.

Preparation and Analysis – A significant number of tests were done to validate the analytical results achieved. These tests reflect the quality of both the sample preparation and subsequent analyses. In general, the robotic cell achieved significant improvements in repeatability as indicated by the standard deviation of repeated analyses on the same material.

Raw Meal – The standard deviation of the raw meal analyses showed considerable improvement. A pre-project typical standard deviation of 1.8 seen in the LSF, was reduced to 1.2. The detail for each of the analyzed analyzed oxides is shown below:

RAW MIX ANALYSIS BEFORE

N=11 Manual

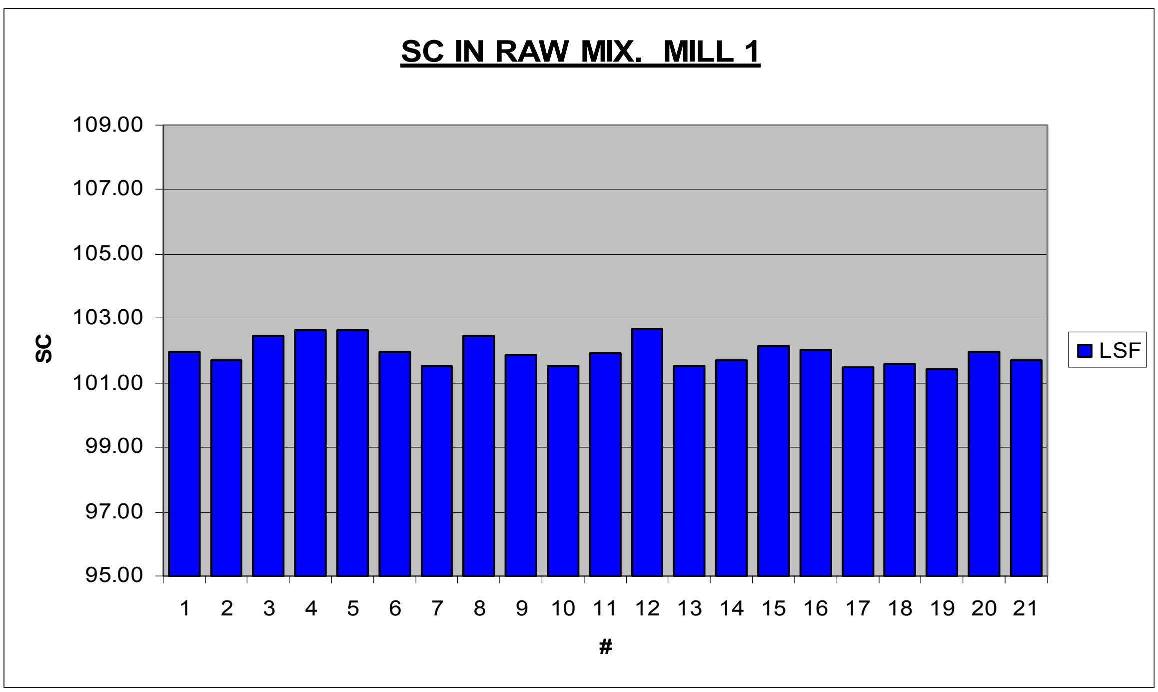
	SiO2	Al2O3	Fe2O3	CaO	MgO	LSF	MS	MA
Ave	13.33	3.19	1.62	41.64	2.38	98.85	2.72	1.98
Std. Dev.	**0.11**	**0.05**	**0.03**	**0.19**	**0.02**	**0.66**	**0.13**	**0.03**
rank	0.31	0.14	0.08	0.53	0.05	1.86	0.34	0.07

RAW MIX ANALYSIS Automatic

TIME: 150s
n=26

	SiO2	Al2O3	Fe2O3	CaO	MgO	LSF	MS	MA
Ave	13.29	3.12	1.58	42.74	1.91	101.95	2.82	1.97
Std. Dev.	**0.06**	**0.01**	**0.00**	**0.05**	**0.01**	**0.41**	**0.01**	**0.01**
rank	0.23	0.02	0.01	0.20	0.02	1.24	0.03	0.02

Graphically, the LSF Standard Deviation (SC) appears as follows:



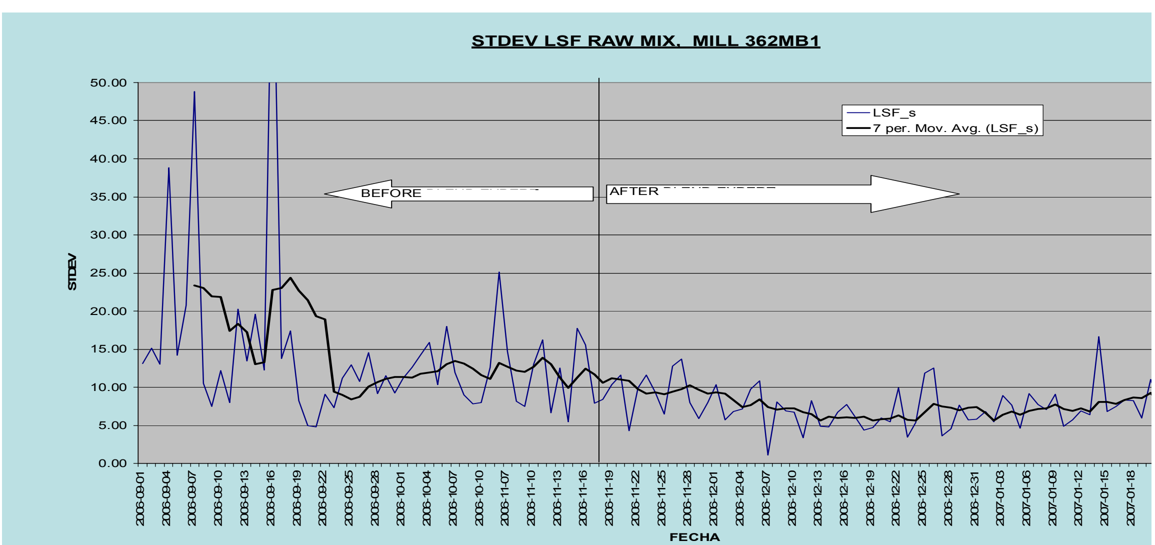
Other key control parameters were similarly improved. These include:

Measured Parameter	Standard Deviation - Before	Standard Deviation -After
Clinker – Free Lime	0.04	0.007
Cement - CaO	1.66	0.16

Control – Analytical precision and accuracy are very important, but the point of the entire exercise is control. With the laboratory project, two major control points were added: pile and raw mix (3 mills). The pile control has reduced the standard deviation of the pre-homogenizing pile by almost 40%. Details of two typical piles are shown below:

	PILA 0108		PILA 0208	
	WITHOUT PILE CONTROL		WITH PILE CONTROL	
	Promedio	DesvStand	Promedio	DesvStand
LSF	112.818	61.608	103.894	39.498
SM	2.825	0.808	2.815	0.752
IM	1.942	0.558	2.077	0.511
TPH	969.452	150.204	966.019	123.086
TPH 2	967.397	155.013	966.764	122.704
SiO2	13.399	3.489	13.452	2.461
Al2O3	3.234	1.070	3.343	0.881
Fe2O3	1.692	0.467	1.641	0.408
Na2O	-1.220	0.460	-1.051	0.380
K2O	0.439	0.234	0.367	0.216
CaO	42.094	3.420	42.032	2.202
MgO	2.200	1.146	2.152	0.926

The results for Raw Mix control, while impressive, show that more work is still required. As often the case with control projects, increased data and control highlights either equipment or process limitations that must be addressed in order to obtain further improvement. In this case, close monitoring of the raw mix chemistry and feeder settings indicate internal variations, thought to be due to material segregation, are limiting the stability of the product from the mills. While segregation is easy to observe, correcting it can often be an involved process. Nonetheless, the automatic laboratory system provides the control adjustments necessary to reduce the variations to within range of blender correction. Typical raw mix control results are shown below:



Conclusions

In short, the project was a success, but there is more work to do. Improved sampling and analytical procedures have increased the amount of data and the quality of the data available for the three cement lines. Reviewing and analyzing this data is an ongoing process and provides an ongoing basis for improved process stability, control and operational quality of the San Miguel facility. Specifically, the following benefits were realized:

- Significant reduction in the deviation of the raw mix
- Significant improvement in analytical precision
- Reduced standard deviation in all measured parameters
- Improved pile formation – less deviation, closer to desired target
- Highly reliable automatic processing – 97 % objective well exceeded
- Shift of focus – from performing chemical analyses to performing data analysis
- Improved skills of lab personnel

The challenge continues, however. An ongoing effort is required to maintain the high levels of operational reliability and analytical precision achieved with this project. Ongoing training and experimentation is required to fully utilize the capabilities of the new system. Most significantly, additional work is required to digest the data available and reflect the lessons learned back into operational and process improvements.