QUARRY MATERIAL USAGE OPTIMIZATION IN REAL TIME
CASE STUDY OF A TOTAL SOLUTION FOR QUARRY AND
STOCKPILE OPTIMIZATION

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Summary

With the pressures on the cement producers to reduce the use of high cost, high-grade materials, extension of quarry lifetime and, at the same time, to maximize output while guaranteeing a constant product quality the need for analytical real-time material characterization and optimization reaches a critical stage. Only a tuned combination of an analytical on-line system with an expert system can guarantee the quarry operation and stockpile optimization with sufficient confidence. Once installed the operation of the quarry and the stockpile pre-homogenization is fully relying on a high availability of such a system. On-line bulk material analyzers using radioactive excitation are available but the reliable supply of the exciting radioactive material has become an issue lately. Several suppliers offer Stockpile blending systems but none of those can offer a fine tuned total solution.

In this paper we will discuss the results and benefits of a total quarry management and stockpile blending solution including an environmental friendly, radioactive free on-line bulk material analyzer together with an expert system for raw-material proportioning. The solution that we present in this paper is based on a real installation that was started in May 2008. The final commissioning of the total system with its various sub systems has be finalized in December 2008.

The situation that was found at the customer site was quite a complex arrangement of 3 quarries. One quarry was a high grade limestone quarry and the other two had highly variable Marl and Clay compositions.

The transport of the materials from the quarries to the crusher is handled by trucks. The trucks need approximately 10 to 30 min to reach the different quarries and two types of trucks are available, a smaller type with 12 tons capacity and a bigger one with 30 tons. The trucks dump the material directly into a hammer crusher.

The task that we were given was the blending of a circular stockpile to a specific Lime Saturation Factor (LSF) by utilizing a maximum of the material coming from the 2 highly variable quarries.

In terms of analysis data we were supplied with bore hole analysis from the quarry. The analysis delay was roughly 12 hours after the samples reached the laboratory. We also had analysis data from samples which were taken.
with a bucket sampler on the belt after the crusher feeding the circular stockpile.

Every 250 tons the bucket sampler did a sweep and collected about 5 kg of sample. This sample was grinded and then split and about 200 g of material went to a composite mixing tank. Every hour 500 g of sample was taken out of the mixing tank and sent to the laboratory. The 30 g of the sample was analyzed by XRF.

The target for the given period of measurements was a LSF of 85. The average of the bucket sampler samples gives a LSF of 75 with a standard deviation of 27. Back calculated raw-meal analysis showed a LSF of 80 with a standard deviation of 12 to 16 after the stockpile.

To improve the control we identified 3 critical areas in the whole set up.

We wanted more reliable faster data. To monitor all the material going to the stockpile a nuclear free bulk material analyzer was installed after the crusher on the belt feeding the circular stockpile. This analyzer uses an environmental friendly light based Near Infrared (NIR) as the analysis technique.

How does NIR work for mineral materials?

When high intensity infrared light hits matter the molecules in the matter start vibrating. The molecules can take 6 different movements and each molecule with a specific movement has a characteristic frequency.

Due to the vibration of the molecules the crystal structure of the material also starts vibrating and adds mineralogical information to the spectrum. The result is a spectrum from 350 nm to 2500 nm, unique in NIR analysis, containing all molecular and mineralogical information about the material that passes underneath the analyzer.
The analyzer was calibrated with sample material from the customer at the factory. The samples represented the full range of material that would be analyzed later on. In NIR a mathematical analytical model is created to represent the reality.

The analytical model was developed using the standard method of partial least square multivariate linear regression (PLS1). This means a sufficiently large training set, in our case 60 customer samples, was used. The key constituents CaO, SiO2, Al2O3 and Fe2O3 were modeled. For each of them a separate model was compiled using PLS1 with a tailor made preprocessing to optimize the respective constituent.

While acquiring the training sample spectra their potential moisture content was systematically taken into account by taking spectra starting with completely dry samples and systematically adding water until the samples were saturated with water. A moisture range from 0 to 20% was incorporated in the analytical model. Mixing the training samples took the effect of statistical variation of the position of the individual training sample member into account.

Every 100 milli-seconds the analyzer acquires a full spectrum. Spectra are accumulated over one minute and the average minute analysis is reported to an expert system.

Based on the analysis of the analyzer the average stockpile composition and LSF value is calculated by the expert system. The expert system includes a raw material proportioning module. The task the expert system has is to fulfill the calculation of the material demand from the quarry. Based on the calculated demands it has to schedule the trucks to deliver the requested material. Basically the expert system is taking the role of the quarry manager.

A study of any group of quarry operators controlling the same quarry will show that certain operators perform better than others, some are better at handling the right blending and some better at achieving the highest throughput. What is common however is that most operators take actions relatively infrequently and react to, rather than predict variations in the process.

A consequence is that stockpiles have high standard deviation on the LSF. An expert system can improve this by firstly, applying the strategy of the 'best of the best' operator without pause, secondly, take actions

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>9 – 30 %</td>
</tr>
<tr>
<td>CaO</td>
<td>35 – 51%</td>
</tr>
<tr>
<td>Al2O3</td>
<td>0 – 5%</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>0 – 3%</td>
</tr>
<tr>
<td>MgO</td>
<td>0 – 8%</td>
</tr>
<tr>
<td>Moisture</td>
<td>0 – 20%</td>
</tr>
</tbody>
</table>

Table 1: Calibration ranges
far more frequently than a human operator and include all available information for the decision.

With the addition of model predictive control (MPC) to the other techniques like fuzzy and neural networks, experts systems with the correct model now have the ability to predict material changes and add this to the blending calculations without having to wait for additional bore hole analysis.

What is truly unique in the application is that we are looking at is the combination of mixed logic dynamics (MLD) with MPC. For the first time binary conditions, such as trucks availability is included in a model that also describes the dynamic behavior of the transport logistics of the quarry.

The total model which was developed for the stockpile blending included:

- Quarry model with 6 different sections in the three quarries representing different material qualities based on initial bore hole analysis.
- Transport model for the trucks, incorporating mass to be transported and time needed for the round trip to specific quarry sections as well as fuel efficiency
- Crusher model, addressing different throughput times for different material mixes
- Stockpile model with stacking strategy and homogenization model

So what does MPC and MLD do in practice?

Based on the minute by minute material analysis of the online analyzer the demand of the material supply from the different sections of the 3 quarries is calculated. When the demanded material from the specific section of one of the quarries is delivered the analysis is compared with the predicted composition and, if necessary, the composition database updated accordingly. To make sure that the received analysis is related to the delivered material following parameters of the crusher and conveyor layout to the stockpile have to be taken into account:

- Crusher model with run through time for the different material mixtures
- Material mixing in the crusher depended on the material mix
- Time delay between material dump and material analysis

After the expert system has verified the material delivery the average LSF value of the stockpile is calculated and the next material demand is scheduled that guarantees that the LSF value of the total stockpile is in the allowed range.

Afterwards the calculated material demand has to be distributed to the available trucks. Following parameters have to be taken into account to schedule the trucks:

- Truck availability
- Truck capacity
- Truck travel time to and from the quarry
- Loader availability at the specific section in the quarry
- Specific fuel consumption of the individual truck

To handle the scheduling a truck database was developed which contains the truck capacity and average runtime to each section of the 3 quarries and the specific fuel consumption of each truck. The truck identification is done by the crusher operator by selecting the

Figure 5: Expert Models

Figure 6: Quarry section color code
dumping truck out of the truck schedule list which then gets automatically scheduled for the new material demand.

The information from which quarry and quarry section the truck should collect the material is given to the truck driver by a color code on a traffic light installed at the crusher building. The information that the loaders have to move to different quarry sections to fulfill the correct loading of the trucks is given by the crusher operator who informs the loader driver by mobile phone.

The installation is now fully operational and the following results have been achieved;

- Marl quarry usage up 3%.
- Truck usage due to less waiting time up 8%
- Truck fuel consumption down by 3%
- Standard deviation of the stockpile feed reduced from 27 to 12 points LSF
- Standard deviation of the reclaimed stockpile reduced from 16 to 5 points LSF

Plans have been made to fully automate the truck scheduling. The first step will be that the color coding of the traffic light will be directly done by the expert system. The second step will be automatic truck identification and an automated message to the loader driver by SMS.