Driving Value Using Closed Loop Optimization Technology At The Williams Ignacio Plant

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ABSTRACT

Williams Midstream is one of the largest gatherers and natural gas processors in the San Juan Basin of Colorado and New Mexico. Williams Midstream operates 5 gas plants in the region with the combined capacity to process approximately 750 million cubic feet per day and treat an additional 760 million cubic feet per day. The Ignacio Processing Plant, near Durango, CO is a large, complex facility with a design processing capacity of 450 million cubic feet per day. Operations at Ignacio are closely coordinated with operations at the Milagro Treating Plant, 50 miles away, to maximize efficiency.

In 2005, Williams Midstream selected closed-loop process optimization technology to improve the profitability of the Ignacio Processing Plant. This paper will outline some of the operational challenges associated with managing the Ignacio facility, and with coordinating Milagro volumes and will discuss how closed-loop optimization was identified as a viable option for helping Williams to address these challenges. The methodology employed to justify the project for AFE purposes will be described.

The Ignacio closed-loop optimization system was commissioned in 2006. The system includes two primary technology offerings:

- eSimulation's eSimOptimizer^{SM} on-line economic / process optimization system applied to a large scope gas processing plant, including a cryogenic gas plant, product fractionation facility, power generation and LNG production
- Multivariable predictive control technology to smooth process upsets and to achieve and maintain the operational targets developed by the eSimOptimizer^{SM} system.

Lessons learned from deploying both of these technology offerings will be discussed. The results of a performance test on the multivariable controller will be presented. Finally, the value methodology used for the benefits assessment will be summarized.

MARKET ISSUES

The San Juan basin produces large amounts of rich gas that must be treated and processed for market, and also large amounts of lean coal seam methane gas which only requires treating. Williams operates 3 gas processing plants and 2 treating facilities within the San Juan basin. The Williams gas processing assets are operationally linked and operated as a supersystem. The Milagro treating facility and Ignacio processing plant are operated in a tightly coordinated way within the supersystem.

The Ignacio plant primarily processes rich gas from the San Juan gathering systems but can also process lean coal seam gas and relatively lean gas from the Williams Northwest Pipeline. The mix of feeds to Ignacio is dictated by economics and operational issues. The Ignacio plant includes:

- Cryogenic gas plant (450 mmscfd design inlet gas capacity) with Ortloff GSP and RSV process capability, that produces Residue and Y-grade products for pipeline sales
- Fractionation train (approximately 15,000 barrel/day NGL processing capacity) that produces Propane, Butane and Gasoline products for rack sales.
- LNG production facility that produces approximately 50,000 gal/day automotive LNG for rack sales.
- Turbine exhaust waste heat boilers coupled with steam turbine generators that provide all normal on-site power and process heat requirements.
- Several direct fired boilers to provide supplemental heat generation when required.
- A mix of centrifugal and reciprocating compressors to boost the inlet gas and residue gas pressures as required.

The plant is located at 6600 feet of elevation in a semi-arid environment so is subject to significant derating of gas turbine power and significant power swings both seasonally and day to night. The facility is well instrumented, and includes a Honeywell Experion control system. Ignacio plant has an experienced, competent and engaged operations staff actively seeking opportunities to continuously improve plant performance. They have a solid grasp of plant economics and objectives.

The Milagro treating plant is located approximately 50 miles from Ignacio and primarily processes lean coal seam gas. The gas is high in CO2 and auxiliary fired boiler systems are sometimes required to be operated at Milagro depending on inlet volumes and CO2 content. At Ignacio, some lean coal seam gas can be treated and bypassed directly to residue blending without further processing but at some additional cost. If the overall CO2 loading at Ignacio is too high, these costs rise. Therefore, an important supersystem objective is to coordinate lean coal seam gas volumes to Milagro and Ignacio to minimize the overall treating costs while meeting pipeline specifications.

Williams' engineering and operations teams evaluated ways to better optimize energy usage and overall profitability on a continuous basis. They selected closed-loop optimization technology as one means of more effectively managing energy and commodity price exposure and to maximize the profitability of the facility under all economic conditions.

OPEN-LOOP VS CLOSED-LOOP OPTIMIZATION

On-line open-loop optimization – as implemented by eSimulation in the gas processing industry since early 2000 – describes a system that periodically processes on-line plant data in a rigorous process/commercial model and then posts suggested optimization targets to be manually entered by operators through their existing control system. The open-loop approach has been well received in the gas processing industry. eSimulation has implemented over 26 on-line open-loop optimization systems and continues to deliver this technology.

The difference between open-loop and closed-loop optimization is in the handling of the optimization targets. In the closed-loop system, the targets are automatically written directly to the process, usually through a multivariable predictive controller whose job is to smoothly transition the process to, and tightly control the process at, the desired operating conditions while honoring all defined process limits. Closed-loop optimization has not been widely applied in the midstream industry but has been applied extensively in large-scale refining and petrochemical processes for over 25 years.

While the open-loop optimization approach has been well received and consistently shown value in the midstream industry, there are additional benefit opportunities for a large complex facility that cannot be fully captured using this approach. For this reason, Williams chose to pursue a fully closed- loop system for the Ignacio facility. The rationale for this approach is as follows:

- The plant is large enough that missing opportunities by not routinely and accurately making optimization moves could be costly.
- The plant is complex enough that holding all of the optimization targets simultaneously could be difficult. To maximize profit usually requires operating the process at multiple constraints simultaneously. With a large complex process, this can be consistently difficult.
- Because of interactions and non-linearity, multivariable predictive control technology in the fractionation train was expected to help the operators to maximize product upgrades and potentially increase throughput when product demand warranted.

- The plant is well instrumented and Williams wanted to leverage the investment in control infrastructure to maximize benefit and competitive advantage.

There are some additional costs for closed-loop optimization. The major addition is the cost for implementing the multivariable predictive controller, but there are also some incremental engineering costs to configure the on-line optimizer to read limits and write targets to the controller. A detailed justification of the overall system costs was required for approval of the project AFE.

ECONOMIC JUSTIFICATION

eSimulation worked closely with Williams engineers and management to develop value metrics for the project and to design a solution that would capture and sustain maximum value. The value metrics were derived following meetings aimed at thoroughly understanding the Ignacio process options, limitations, and commercial economics. Using this understanding, process data was reviewed to estimate the expected improvements from a properly designed, implemented and maintained closed-loop optimization system.

The statement of objectives as was approved in the Ignacio AFE document is as follows:

> "This system will determine the financially optimal configuration of the Ignacio plant and associated systems. These changes will be implemented automatically using a Multi Variable Controller (MVC). This MVC will reduce plant variability and process noise which will increase efficiency. The advanced predictive control will also allow desired setpoints to be reached much more quickly than conventional controls and with much less disturbance to the system. These characteristics will allow the MVC to drive plant process variables towards constraints in an effort to maximize yields, flows, and spec limits. The Optimizer model will also provide continuous performance assessments on key equipment in the plant (i.e. exchangers, compressors, process vessels, etc.). This will assist in maintenance and operational decisions on when and how to perform maintenance."

The Ignacio closed-loop optimization project was approved based on the resulting benefits projections. eSimulation won the bid to implement the system.

TECHNOLOGY

The Ignacio Closed-Loop Optimization system consists of two major technologies integrated to work as a single coordinated system. An on-line optimization system develops optimal operating targets and a multivariable predictive controller enforces the optimal targets. These two technologies are briefly described below.

On-line Optimization

The economic optimization and process modeling are performed by eSimulation's proprietary eSimOptimizer^{SM} system. eSimOptimizer^{SM} encompasses a number of key components including:

- Rigorous chemical engineering process modeling and flowsheeting capabilities (mixers, splitters, distillation trays, heat exchangers, compressors, expanders, etc.)
- Detailed profit model including calculations for all common commercial contract arrangements between producers and processors (POP, POL, KW, FEE, etc.)
- OPC client to collect data from OPC-compliant control systems and store in eSimulation's proprietary database
- Proprietary I/O capability between modeling system and database
- Web interface for manual data entry and for viewing all data in database via standardized views or custom web-pages

eSimOptimizer^{SM} has been described extensively in previous GPA papers. One key feature that we highlight again here is that the model is built in 'equation-based' form and solved using a commercial optimization engine. This formulation is uniquely suited for the requirements of an on-line optimization system because it allows the model to automatically adapt to changes in plant configuration or performance at each optimization cycle, and allows the simultaneous solution of the optimization and simulation problem to produce more timely and robust results.

Multivariable Predictive Control

Multivariable predictive control technology has been commercially available for more than 30 years and has been applied extensively in the refining and petrochemical industries. There are several competing packages available. While each is unique, most share the following features:

- Use an explicit, empirically-derived, linear, dynamic process model relating each controller input (manipulated or disturbance variable, MV or DV) with each controller output (controlled variable, CV) over a future time horizon (time to steady-state)
- Use an optimization algorithm to derive the 'best' set of simultaneous moves for each MV to minimize the difference between each CV and its target over some time horizon while satisfying all defined limits on CVs and MVs (high, low, rate-of-change)

- In the case where there are more MVs than are required to achieve the CV targets, the excess degrees of freedom may be ‘optimized’ by some sort of pre-defined criteria – this is often confused with economic optimization but in practice is usually not the same

Beyond the basic functionality, multivariable predictive controllers usually include the capability to apply variable transformations to linearize non-linear variables like valve positions and analyzer signals. In addition, calculations may be included to infer some variables from others. An example would be an inferred continuous composition from measured temperatures, pressures and flows. This sort of inferential would normally be updated using a discontinuous analyzer signal.

Multivariable predictive controllers add value by reducing process variance through tighter, more highly coordinated control. By reducing process variance, the process targets can be shifted closer to limits. This shift allows the controller to decrease product give-away and increase production. Multivariable predictive controller benefits are well documented in the process industries. Typical performance improvements include a 50% or greater reduction in process variance and a 2% - 3% increase in production for throughput constrained units. The combination of a non-linear on-line economic optimizer and multivariable predictive controllers allows the true process optimum to be dynamically calculated and closely enforced to maximize the economic efficiency of the plant.

eSimulation chose a new multivariable controller technology for the Ignacio project. It was understood going in that the controller development schedule presented some schedule risk for the project but it was felt that the reduced maintenance requirements and better long-term performance promised by the new technology would be worth the potential delay in implementation.

IMPLEMENTATION

The on-line optimizer and multivariable predictive controller were implemented in parallel to initially form an open-loop optimization system. Prior to closing the loop, the operator would manually implement the optimization targets through the multivariable predictive controller. This was the fastest path to achieving project benefits and allowed the operators to become familiar with what the optimization is doing and to validate the optimizer and controller performance. Once the results were fully validated, the loop between the optimizer and the controller was closed so that the optimization targets would automatically be implemented to the controller without operator intervention.

On-line Optimization

The Optimizer project team followed the standard approach for deploying eSimOptimizer^{SM}. A kickoff meeting was held at the plant to gather required information to begin modeling, including latest P&IDs, compressor and expander design information and performance curves, heat exchanger design sheets, instrumentation lists, design material balances for each mode, and snapshots of current plant performance. Subsequent meetings were held with the commercial group to nail down the requirements for implementing and maintaining the economic model of the plant.

A followup visit to the plant was taken to install a computer and software to interface to the plant control system and to initiate dataflow from the plant to our common database servers. eSimulation configured its proprietary DataPumpTM application to collect the required temperatures, pressures, flows, speeds and compositions, along with other selected signals from the control system.

Using the eSimOptimizer^{SM} modeling system, a rigorous steady-state chemical engineering model of the process was built. The scope of the model included inlet compressors and treating, inlet gas chilling and separation, propane refrigeration system, expander and JT valves, demethanizer and absorber columns, booster compressor, LNG facilities, residue compressors, deethanizer, depropanizer and debutanizer. In addition, all steam producers (waste heat and fired boilers) and steam consumers (power generators and reboilers) were modeled. The three-level steam header system was modeled and fully integrated with the process model and fuel gas models to complete the heat and material balance. Finally, the blending of various streams forming residue and y-grade products is modeled.

Once off-line modeling was complete, the model was interfaced to the database (both live instrument values and manually entered limits and commercial values) and the data reconciliation problem was tuned so that it gave reliable/robust model parameters. The optimization problem was tuned to robustly solve for the process targets that would maximize plant profitability. The results were reviewed with Williams to make sure they were valid and well-understood. Once this initial formulation and tuning of the model was completed, it was placed in on-line service and the optimization results posted to secure custom built web pages at each cycle for operator action.

As previously stated, the open-equation modeling approach allows the model to adapt to changes in configuration. The Ignacio plant frequently switches between RSV and GSP mode based on economics and plant capabilities. Less frequently, the plant may switch into Rejection operation when C2 margins are not favorable. The model is configured to detect these switches automatically and reconfigure to the new lineups and different tuning for each mode of operation. The model robustness was initially good but not at the desired level. As part of the support strategy for the application, eSimulation continues to monitor and improve model performance and the current robustness is approximately 95% success rate which is excellent for this type of application.

Multivariable Predictive Control

The Control project team also followed a standard methodology for implementing multivariable predictive control technology. The most important step to a successful implementation is the Plant Test. The Plant Test is labor-intensive and the data collected during the test is used to develop the dynamic process models. The quality of the dynamic process models ultimately determines the quality of the controller performance so it is important that the test be conducted efficiently and effectively.

During the Plant Test, the Manipulated Variable candidates for the controller are deliberately moved to generate a process response. The empirical dynamic response models for the controller describing the dynamic response of each controller CV to each controller MV and DV will be developed from the collected response data so it is critical that the test plan be well-understood. In addition, the Plant Test often places some additional burdens on the operators and laboratory personnel so it is important that everyone knows what is required for a successful test.

Following completion of the Plant Test, the preliminary models are refined and validated through detailed model identification. This step includes finalizing the development of inferential models and variable transformations. Based on the results of the model identification, the controller design is further refined, the proposed controller is configured (along with its user interface), tested and tuned off-line.

The final step is Commissioning. In this step, the controller is placed in service and control performance is observed. The operators are trained in the use of the controller at this time. The controller is fine-tuned as required to get the desired setpoint response and disturbance rejection capability over a range of operations.

Closed Loop Optimization

The Open-loop Optimization was implemented and providing benefits for several months prior to closing the loop with the controller. During this period, the optimizer was being tuned to give better results and the controller was being commissioned and tuned to better enforce the optimization results while responding to normal day-to-day plant disturbances. Once the controller was commissioned, closing the loop with the optimizer was a non-event since the operators had been implementing the optimizer targets manually through the controller all along by setting controller External Targets.

External Targets can be thought of as setpoints for the multivariable controller CVs. They may be used to allow the operators to target certain variables (like deethanizer feed rate) or as an interface to a rigorous non-linear optimizer (eSimOptimizer^{SM}). The controller doesn’t know or care whether the target is a manual entry from the operator or an automatic download from a detailed economic optimizer. It simply enforces the External Targets that are set. This is how the Open-loop Optimization targets were set prior to closing the loop.

To ensure consistency between the On-line Optimizer and the Controller, eSimulation configured eSimOptimizer^{SM} to read all Controller limits and optimize within those bounds. The eSimOptimizer^{SM} results are written out to a database. A special software interface takes the eSimOptimizer^{SM} targets and performs validity checks before passing them down to the multivariable controller. The controller performs its own validity checks as described above prior to moving the process to the optimal targets. There were initially a couple of iterations on the fundamental logic for shedding External Targets in the case of infeasibility but the system as described here has worked well.

Support Services Strategy

The number one reason why on-line applications fail is that they degrade over time because of changes in plant performance, changing in plant configuration or changes in software. As the application loses validity or robustness, the operators lose confidence, and the applications are either turned off or ignored. Starting in the year 2000, eSimulation pioneered a different approach for On-line Optimization support whereby the services required toensure that the system continued running, matching the plant and producing actionable results were included for the contract term. For the Ignacio Closed-loop Optimization system, eSimulation extended this support strategy to also include the multivariable controller.

RESULTS

The project was kicked off in February 2005. eSimOptimizer^{SM} was initially placed in service in December, 2005. Full on-site commissioning occurred in February 2006. A preliminary analysis was done in March 2006 based on February data to get a general idea of the value being generated by the optimizer and the source of that value. A repeat analysis was performed in July 2006. These results were consistent with the AFE projections, which coupled with anecdotal evidence, suggested that we were on the right track and delivering expected value with the optimizer.

As mentioned, eSimulation selected a new controller product for this project. The initial version of the controller was still under development at the time the project began and unfortunately, took longer than expected. This resulted in many commissioning issues and delays, and though the problems were overcome, the delays and software issues reduced operator confidence in the system. Once the software issues had been resolved, eSimulation worked diligently with Williams' engineers and management to regain operator confidence, and by July 2006, the controller for the fractionation train was successfully commissioned. The loop was closed between the optimizer and the controller in September, 2006 and the completed system has been running well since then.

Because of the implementation issues encountered with the controller, and the long time-frame over which the controller and optimizer were implemented, there was some doubt from the operations staff with regard to whether the controller had actually achieved improved control on the unit and whether other functional objectives of the control project had really been met. To satisfy these concerns, a rigorous performance test for the controller was conducted in November 2006. Also, a detailed third-party post-audit of the system economic performance was initiated in December 2006.

Multivariable Controller Performance Test

To isolate the multivariable controller performance the optimizer was turned off and the external targets for key composition variables and frac feed were set directly by the operators. The following criteria were used to evaluate controller performance for the test:

- Did the controller respond to the new targets in a smooth and repeatable manner?
- Were other key controlled variables in the controller (e.g., levels) controlled satisfactorily?
- Were the response times to target changes reasonable (this is usually made in reference to the response time of the process without mvc control)?
- Were the averages of key composition variables held close to target values?
- Do the average deviations of the key composition variables represent improvement over non-mvc operation)?

The controller achieved targeted changes in compositions and feed rates in a smooth and repeatable manner. Response times for each variable were shorter than the corresponding open loop response times. Other dependent variables were well controlled throughout the test. Averages and average deviations of the controller composition variables are shown in Table 1:

	All test data		**Test data without target changes**	
	average	avg. deviation	average	avg. deviation
Key variables				
Propane vapor pressure	207.7	0.85	208.2	0.85

Propane total C4s	2.2	0.09	2.2	0.06
RVP (predicted)	10.5	0.08	10.5	0.02
Butane total C5s	12.2	2.4	12.1	2.4
Other variables				
DeC2 Bottoms C2	5.75	0.42	Not Applicable	Not Applicable
Propane C2	6.23	0.25	Not Applicable	Not Applicable

Table 1. Key test variables.

The data above as well as the observed responses during the test confirmed that the controller was working well and the objectives of the control project had been met. An example response is shown in Figure 1.

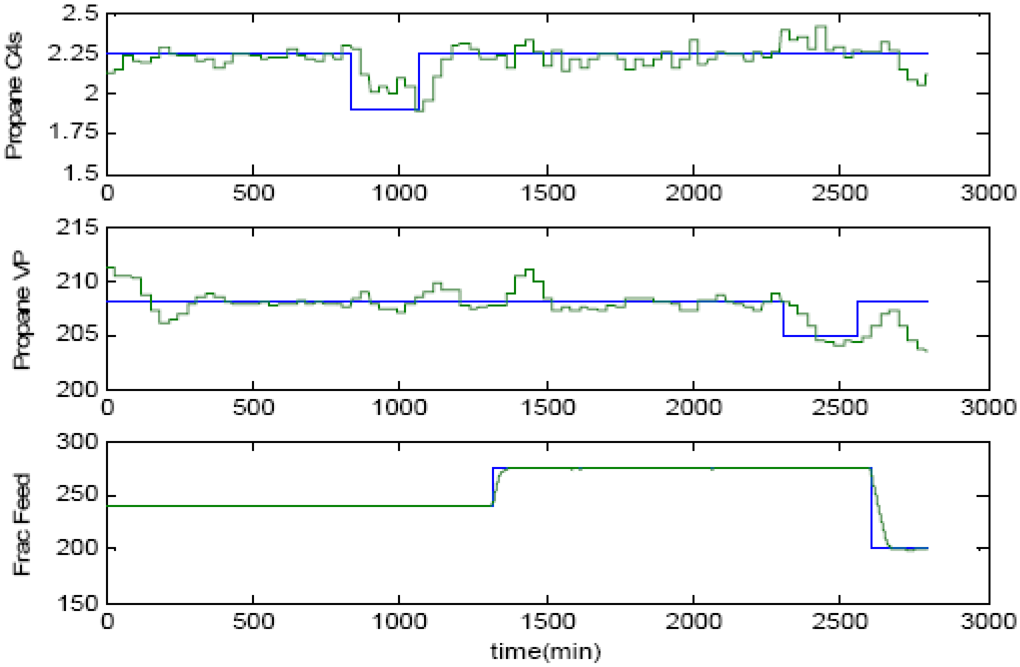

Figure 1. Key test variables. Test started at time =0 when controller was switched on; test was stopped at time = 2985 after a loss of recompressor

Combined eSimOptimizer^{SM} / Multivariable Controller Value Assessment

To further confirm that the economic objectives of the project had been met, Williams engaged a third-party engineering firm in December, 2006 to assist in finalizing the value assessment methodology and independently confirm previous benefits estimates. Meetings were held at Ignacio in early-January, 2007 to collect base-case and post-implementation data for evaluating the benefits.

The difficulty in performing an economic audit of a process automation project lies primarily in establishing proper data for comparison. This task is particularly difficult in the case of NGL plants because plant objectives, performance and constraints change frequently in response to changes in commodity economics, product demand, gas supply, ambient conditions and maintenance activities. Extreme care and engineering judgment must be taken to ensure a fair comparison as we are generally looking for relatively small differences in relatively large numbers.

Once the appropriate datasets were identified a rate-normalized material balance comparison was developed to identify physical changes in operations. The economic value of the resulting physical changes was computed by applying the true commercial structure of the gas and product contracts governing Ignacio plant accounting. No attempt is made to distinguish control benefits from optimization benefits. The two systems work in tandem to achieve the profit and separating the benefits does not make sense. The specific calculations and results are proprietary.

SUMMARY

An On-Line Closed-Loop Process Optimization system has been successfully implemented at the Williams Ignacio facility. The system includes a rigorous process model-based economic optimizer which writes targets directly to a modern multivariable predictive controller. Performance tests have shown that the system is generating significant value for Williams and the associated services contract ensures that value will continue to be delivered and enhanced throughout the life of the system.