Originally appeared in HYDROCARBON PROCESSING® January 2000, pg 15-16. Posted with permission.

H P In Control

Y. Zak Friedman, Guest Columnist

Closed-loop optimization update—a step closer to fulfilling the dream

Closed-loop economic optimization of refineries and chemical units has been a dream in our industry for over four decades. There have been at least three waves of attack on this problem, but optimization has resisted the onslaught and remained a dream. Having witnessed a number of unsuccessful online optimization projects, I wrote several papers[1,2,5,6,8,10] suggesting that closed-loop optimization needs certain technological breakthroughs to be viable. However, recently there have been some refreshing new developments. This editorial tones down the negative language and expresses hope that, while there are still many difficulties, we are now a step closer to fulfilling the dream.

Starting around 1990 and until about a year ago, closed-loop optimization has taken the following format.

- A linear multivariable predictive controller (MVPC), handling the advanced control part of the application, pushes the plant against constraints, while keeping product qualities at targets. The practice has usually employed large MVPCs, often only one to handle the complete plant.
- Statistical regression models infer product qualities, serving the MVPCs as virtual analyzers.
- A steady-state rigorous simulation model searches for optimal plant settings and downloads those settings as MVPC targets.
- The steady-state model requires steady-state input data. Most applications wait several hours between each process change to ensure steady state.

Although orchestras of papers[3,4,7,12] have trumpeted closed-loop optimization, reality on the ground was that these applications were labor-intensive, difficult to develop and fell apart easily. In my publications, I have offered a number of reasons for why the technology did not work.

1. There is a lack of procedures for estimating intermediate product prices. A unit cannot be optimized in isolation unless its product economics are known.

2. Inability to define unit feed makes it impossible to predict product qualities. Even the best rigorous simulation would be useless unless feed characteristics are known.

3. Infrequent optimization runs are incompatible with the operational desire to change constraints and targets in small steps. Designing the applications to wait for a "steady state" set of data is strange, because MVPCs are able to forecast the eventual resting values of all process and manipulated variables. But that is the way most applications have been configured.

4. Effective optimization requires detailed, accurate models and complex simulations. That presents a problem of first developing high-accuracy models with hundreds of thousands of equations and then keeping track of those models and maintaining them in a working environment.

5. Linear MVPC technology has a hard time with real-life nonlinear units. Practitioners of this technology have dealt with this problem by detuning the controllers. This is perhaps OK for holding the unit at steady state. However, online optimization requires moving the unit smoothly along constraints from one steady state to another, while controlling product qualities at targets. A detuned MVPC cannot be both quick and precise at the same time.

6. This detuning problem is exacerbated by size. Large MVPCs are exponentially more difficult to tune than medium-sized ones. I have not seen a single large MVPC that performed well dynamically.

7. Linear MVPCs are usually equipped with a linear optimizer (whose task is not to optimize but to prioritize constraints). Coordination between the rigorous optimizer and the linear MVPC optimizer is awkward.

8. Statistical regression inference models, which ignore chemical engineering principles, need frequent recalibration and too much laboratory support to perform well. Again, when the unit is kept at steady state for long, the models could be biased based on laboratory results. But in a dynamically unsteady constraint control and optimization environment, reliable quality prediction is crucial.

9. Shortage of people. In the current environment of "streamlining," plants are badly short of engineers and have hope of maintaining only the simplest applications.

The next interesting development was a kind of optimization application called "composite LP." Many practical workers in the field have shelved their desire to optimize the plant via a steady-state rigorous simulation and moved to solve a more manageable problem.[9] The composite LP application typically contains several MVPCs, each looking at a very local set of constraints. The LP coordinates how a plantwide constraint would be handled among the different MVPC controllers. For example, a constraint on distillation equipment can be relieved by:

- Reducing feed
- Changing yield pattern or plant severity
- Changing feed composition (if possible)

- Relaxing product specifications (often possible when the product is not final)
- And possibly other mechanisms, depending on the specific situation.

Economically speaking, this technology is not a proper optimization technique because it relies on approximate linear models rather than rigorous ones. Also, most MVPCs are already equipped with LPs and, on the face of it, all that has been achieved is an extension of the LP to cover several MVPCs. However, this development has brought about important changes, which later permitted nonlinear rigorous optimization.

- Practitioners of composite LP technology did away with the steady-state wait, designing the optimizer to input future steady-state data predicted by the MVPCs. The optimizer can now run every minute, moving the unit in small steps. As stated, this prediction of steady- state inputs does not necessitate composite LP, but somehow this change came about as a part of composite LP applications.
- While LP formulation often oversimplifies the models, it permitted the later application of successive LP, which is a good method of solving nonlinear problems, especially when small steps toward the optimal solution are necessary.
- Control engineers can now work with reasonably sized MVPCs and still maintain a global view of the plant. Smaller MVPC size would permit better controls underneath the optimizer.[11]

Lo and behold, at the last NPRA Computer Conference we finally heard a paper[13] that describes application of successive composite LP on an ethylene plant. This system applies rigorous plant models, but only for calculating partial derivatives and updating LP matrices to current working points. Composite LP and MVPCs do the rest, driving the plant in small steps toward the optimum. The process repeats once per minute, continually nudging the plant to better operation. Once partial derivatives are available, as an added bonus, the system also updates MVPC gains on the fly, eliminating the need to detune the controls. The double existence of two optimizers—one at the MVPC level and another at the rigorous optimizer level—is also gone. The composite successive LP is the only optimizer.

I have listed nine sticky issues that made the closed-loop optimization problem seem insurmountable in the past. Following are the issues that have not yet been solved and are still a hindrance to the successful implementation of closed-loop optimization.

1. Lack of procedures for estimating intermediate product prices. Perhaps successive composite LP technology can use larger set-ups and group together several units. The work described at the NPRA conference took an ethylene plant as one unit with known product economics. But eventually for a more general situation, unit optimizers must be supplied with marginal product economics for the unit. This is essentially a scheduling issue that has also been an unfulfilled dream—a subject for another editorial.

2. Estimating unit feed properties is still a problem. Partial derivative, matrix gains and LP coefficients are all functions of feed properties, and no model can give reliable results if the unit feed is unknown. Some authors[12] have employed a complex laboratory and bookkeeping system for monitoring and forecasting FCC feed properties. However, I believe that such an approach is of limited use. The only solution that could work seamlessly for closed-loop optimization would involve automatic feed detection, either by on-stream analyzers or inferential formulae.

3. Effective optimization is still limited by availability of good models. I have not made an attempt to evaluate models applied in the specific case, though I've discussed modeling problems specific to ethylene manufacturing elsewhere.[10]

4. Accurate, first-principle inference models are still a problem. The economic drive usually calls for increasing throughput, while maintaining product yields and qualities at targets. Throughput increases accompanied by yield reduction or off-specification products do not necessarily make money. We sometimes can use analyzers in lieu of inference, but the slow analyzer response makes it difficult to apply even constraint control, let alone optimization.

5. Shortage of people is still a huge problem. Managers who would like to bask in the glory of closed-loop optimization should understand that it is incompatible with "streamlining."

While there are still very significant issues, their number has dropped in half, and some objectionable practices have been eliminated. Is closed-loop optimization possible today? Perhaps at some sites it could be, depending on specific site configuration and ability to address the still very sticky five dilemmas stated above. What I want to do is not encourage people to rush and implement $5 million optimization projects, but to simply say that we have made progress with a problem that in the past seemed insurmountable.

LITERATURE CITED

[1] Friedman, Y. Z., "Avoid advanced control project mistakes," *Hydrocarbon Processing*, October 1992.

[2] Friedman, Y. Z., "What's wrong with closed-loop optimization?," *Hydrocarbon Processing*, October 1995.

[3] Pedersen, C. C., D. R. Mudt, J. K. Bailey, and J. S. Ayala, "Closed Loop Real Time Optimization of a Hydrocracker Complex," NPRA Computer Conference, November 1995.

[4] Hardin, M. B., R. Sharum, A. Joshi, and J. D. Jones, "Rigorous Crude Unit Optimization," NPRA Computer Conference, November 1995.

[5] Friedman, Y. Z., "Advanced process control—It takes effort to make it work," guest editorial, *Hydrocarbon Processing*, February 1997.

[6] Friedman, Y. Z., "Advanced Control—What Works, What Doesn't, Where's the Money", Presented at AIChE Houston Chapter Meeting, February 1997.

[7] Kossman, W., H. Besl, T. J.Crowe, and M. Karacotsios, "Closing the Loop: Innovations for Naphtha Complex Optimization," NPRA Computer Conference, November 1997.

[8] Friedman, Y. Z., "More about closed loop optimization," A guest editorial, *Hydrocarbon Processing*, August 1998.

[9] Jakhete, R., W. Rager, and D. W. Hoffman, "Online Implementation of composite LP optimizes FCCU/GPU complex," *Hydrocarbon Processing*, February 1999.

[10] Friedman, Y. Z., "Advanced Control of Ethylene Plants, What Works, What Doesn't and Why," Paper presented at the Ethylene Producers' Committee, March 1999, later published in *Hydrocarbon Asia*, Jul/Aug 99.

[11] Korchinsky, W. J., W. T. Hoffman, and D. W. Hoffman, "Tips for Control Engineers," *Hydrocarbon Processing*, September 1998.

[12] Georgiou, A., F. J. Krambeck, C. T. Cheng, C. Hene, and M. Frederickson, "Closed Loop Real Time Optimization Reaps Economic and Operations Benefits for FCC–Alky Complex," NPRA Computer Conference, November 1999.

[13] Nath, N., Z. Alzein, R. Pouwer, and M. Lesieur, "On-line Dynamic Optimization of an Ethylene Plant Using Profit Optimizer," NPRA Computer Conference, November 1999.

***The author** is a principal consultant in process control and online optimization with Petrocontrol, New York, New York. He specializes in the use of rigorous simulation for inferential control models and has developed a number of simulation-based inferential models. Dr. Freidman's experience spans more than 30 years in the hydrocarbon industry, working with such employers as Exxon Research and Engineering and KBC Advanced Technology. He holds a BS degree from the Technion—Israel Institute of Technology, and a PhD degree from Purdue University.*