TECHNICAL ARTICLE

How Can We Improve Operator Trust in PID Controllers?

By Dan Warren, Michel Ruel, Peter Morgan, Nick Sands, Pat Dixon and Greg McMillan (a whole bunch of ISA fellows)

The following technical discussion is part of an occasional series on https://blog.isa.org that showcases the ISA Mentor Program, authored by Greg McMillan, industry consultant, author of numerous process control books, 2010 ISA Life Achievement Award recipient, and retired Senior Fellow from Solutia, Inc. (now Eastman Chemical). Reprinted by permission.

We start off with a question from Danaca Jordan. Danaca is a founding member of the ISA Mentor Program and serves as VP of ISA's Professional Development Department. Outside ISA, Danaca is a Digital Manufacturing Center of Excellence engineer for a major specialty chemical company, where she drives enterprise-wide digital transformation implementations focused on manufacturing data.

Danaca Jordan's Question

As our controllers get more complex, what are the options to convey what is happening behind the scenes to an operator who must trust the controller?

Dan Warren's Answer

Interesting question. And one that I have had lots of experience with. For me, it has been simple education. But the education, as well as examples, have to be along the lines people will understand. There is no use trying to explain the complicated algorithms or math that we (unfortunately) sometimes tend to bog ourselves down with.

I have heard more than enough references to smoke and mirrors or black box systems than you would care to imagine. So I do my best to use examples from day-to-day life—like say, for example, driving a car. Plus, even though most facilities like to do group training, I find it more effective doing one-on-one. This way, the individual pays attention, asks questions, and doesn't feel as embarrassed or awkward about asking a question or clarifying a statement. Plus, I make myself available on the plant floor as often as I can. In this way, I make myself as approachable as possible. But I also make sure that we are in a safe location when explaining.

Also, it's good to not get things too complicated. Keep things simple, and pick on one scenario at a time.

Michel Ruel's Answer

Some basic principles:

- Explain the goal and the objectives; not what is under the hood, but what it does
- Work with operators; always add extra time to your projects for one-on-one training
- Use example from day-to-day life: air-conditioning, car driving, and so on
- Train the trainers with the approach above
- Design user interface with tips explaining the purpose of counterintuitive actions
- For example, if you added a function unusual to the operator, explain it or add an extra element to explain it on the human machine interface (HMI)
    - E.g., SP filter, add a dashed line showing what is sent to PID controller
    - E.g., replace the arrow displaying SP by the allowable range if a level loop is tuned for absorbing variability
- Spend time with the operators and have fun with them

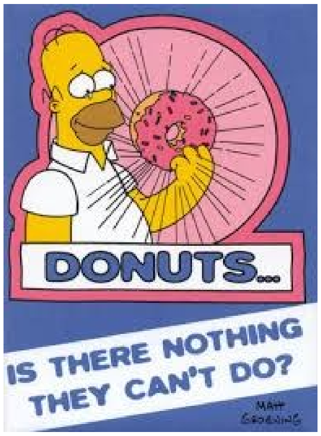
Peter Morgan's Answer

It's important to treat the operator as **both a partner and a client** in providing control solutions—a partner because they can share insights on process behavior; a client because after all is said and done, the operator has to live with the solution.

Engaging the operator in providing solutions—in particular with respect to operator interface and other HMI provisions—while having practical benefit, can add to the confidence the operator has in the automation system and helps build a **relationship of trust** between the operator and control specialist.

Nick Sand's Answer

Take time to build the relationship with the operators to start with. In our in-house training class, this section is subtitled "The Power of Doughnuts." Spend time with them routinely, **just to check in**.



For existing control loops, monitor and assess the performance. If the operators do not trust a controller, there could be a good reason why (such as tuning or valve sizing). Talk to the operators to find out what they see as an issue, and what they might suggest as a solution.

For new control loops, relate the loop's function to how the operator would take action manually. **Good control loops make life easier for the operator.** If they see that, they will be motivated to accept it. Track the loop's performance and utility and follow up on issues.

And follow the top rule for tuning and other modifications—don't make a change on a Friday unless you plan to work the Saturday.

Pat Dixon's Answer

Trust is lost when something doesn't work or doesn't meet expectations. We know that there is an unfortunate abundance of loops that were never well-tuned, or were not maintained. The best solution is to fix them. In other cases, something may be performing to the control engineer's expectations, but not the operator's expectations. That is a case of communication to understand what the operator sees, how they perceive it, and **seeking common ground**.

The question asks about controllers getting more complex. It does not specifically say PID control is more complex. It should be no more complex that it has ever been. Of course, new features have been added that can make the configuration for a control engineer more complex, but for the operator, there should not be any more complexity to a PID. They should actually be better able to visualize faceplates and trends than in the past.

I suspect the more complex controllers that are being referred to are advanced loops with feedforward, cascade, or predictive control. If you have a large matrix in a multiple input multiple output (MIMO) controller, it is understandable why it is more complex. Especially when an optimizer is moving things based on criteria that the operator may not understand, it can become challenging. Getting good performance from the controller, while spending the time with operators to gain common understanding, is a bigger job in these cases than with a single loop, but the same remedy works.

Lastly, there need to be reasonable expectations of what operators should have to know. Explaining algorithms and configuration is not likely to be helpful. Therefore, I do not think the operators need to know what is behind the scenes. Their scene needs to make sense to them.

Greg McMillan's Answer

It is quite a challenge because of little fundamental understanding of process dynamics and the basic action of proportional, integral, and derivative modes that varies with Form and Structure. On top of this, we have the many additional features of setpoint weight factors and lead-lag, and strategies such as cascade, feedforward, ratio, and override control. There is a rough draft of an ISA-5.9 Technical Report "PID Algorithms and Performance" that automation engineers could use to bring themselves up to speed, which is a critical step because most PID controllers are not tuned as well as needed, and most capability of the PID is underutilized.

All of this leads to legitimate lack of confidence in the PID. A digital twin with simple dynamic process simulations could help enable an automation engineer to build their foundation of knowledge and improve the existing PID controllers. Some simple scenarios can be used to provide some hands-on-learning to increase knowledge and appreciation of PID control. Extensive operator input on what is needed during startup and transitions and how to deal with abnormal operation can be used to automate the best of their actions and knowledge as changes in PID modes, outputs, and setpoints via procedure automation and state-based control. The Control Talk column "Continuous improvement of continuous processes" describes these opportunities.

The concepts and actions are similar to what needs to be done in fed-batch control. Testing and training is critical to make sure the PID controller can deal with all types of scenarios. The repeatability gained can enable continual improvement by again seeking operator input. We can elevate the role of the operator to be one more of supervisory control and a source for ongoing improvement that can accelerate with practice. The benefits of digital twins for training and embedding operator knowledge are well-recognized. We just need to open our eyes and expand our minds to think of simulation as a continual learning experience for everyone who plays a role in the automation system success. **We should not underestimate** the capability of operators to learn concepts and their appreciation of a greater understanding of what the automation system and process is doing.

Online process metrics that show process efficiency and capacity can help operators realize the benefits offered process control improvements the consequences of the PID not being in the highest mode. There are some challenges to make sure inputs are synchronized with outputs, there is no inverse response, and the signal-to-noise ratio is good. A moving average helps address these issues. These metrics should be developed and tested in the digital twin typically with the model used for operator training.

Spending as much time as possible in the control room and becoming good friends with the operators goes a long way toward building relationships and mutually beneficial conversations. Bringing in food helps (e.g., po'boys work well in Louisiana). If they share some of what's cooking in the kitchen, you know you are "in good." I especially loved the Cajun food.

Humans have difficulty realizing that an action done now will not be seen in process response until after one total loop dead time, and that the rate of change can be quite slow—particularly for near and true integrating processes. This plays a big role in operators trying to manually control a process and their concerns about what a PID is doing.

In two control rooms, I have had operators say there is something wrong with the PID because on reactor heat-up with split range control, the coolant valve opened when the temperature was below setpoint. If the operator could see the trend and realize that, due to dead time, the coolant valve needed to open, they would not have complained. Integral action would not open the coolant valve until the temperature rose above setpoint, but this would be too late, causing detrimental potentially unsafe overshoot. Proportional and derivative action provides the anticipatory action needed. For this and other reasons, reset action is often orders of magnitude too large and gain action too small. The digital display on faceplates reinforces a lack of understanding of anticipatory action needed.

I think a particularly effective confidence builder would be a smart trend built by automation engineers that would **clearly show the slope** and include, via a dead time block, **predicted values** that progress from current value to at least one dead time into the future. The predicted values are simply a slope multiplied by time increments added to the current value. The slope is the input of the dead time bock minus the output divided by the block dead time. The block dead time may be increased from the total loop dead time to provide better signal to noise ratio and recognition of slope for slow rates of change. The dead time in the response to a small setpoint change is fairly easy to identify, and an exact value is not important for the slope and predicted values.

Oscillations can be detected and probable source identified to correct problems and reduce confusion and loss of confidence and imaginary solutions that are a distraction, wasting time. Some fixes and guidance by automation engineers are possible from some simple observations.

- If the oscillations occur in manual, they are due to another loop oscillating or noise
- If the oscillations in auto are constant amplitude, they are limit cycles most likely caused by valve or variable frequency drive dead band or resolution
- If the oscillations in auto are decaying, they are most likely due to tuning
- If the period of the oscillations is close to four times the dead time, the oscillations are most likely due to too much proportional action
- If the period of the oscillations is five to 10 times the dead time, it is most likely due to too much integral action
- If the period is much larger than 10 times the dead time for processes that are ramping with no deceleration in four dead times, there is too little proportional action and too much integral action; in many cases, simply trying a significant reduction in integral action may confirm the problem

For **feedforward** or **ratio control**, a response to these control actions that occurs before or after and is the opposite of the process response trying to be corrected, the feedforward or ratio control action is arriving too soon or too late, respectively. Fixing this builds operator confidence.

Override control is confusing to operators and engineers. Some calculations can help. The time during the last batch or last shift that each controller was selected can show the controllers and their process variables most significantly limiting process performance possibly leading to some better setpoints or better equipment or operating conditions. Also, a predicted PV at which point each override controller would be suspected of taking over could be displayed.

If you have a digital twin with a high-fidelity real time simulation running in sync with same setpoints of the actual plant, there could be an option of temporarily running faster than real time to see what is going to happen. This could be used offline as well to achieve a much greater confidence in what the PID controller is doing for different scenarios and how the operator can spend more time thinking of improvements, rather than dealing with moment-to-moment changes.

Additional ISA Mentor Program Resources

See the ISA book *101 Tips for a Successful Automation Career* that grew out of this Mentor Program to gain concise and practical advice. See the *Control Talk* column How to effectively get engineering knowledge with the ISA Mentor Program protégée Keneisha Williams on the challenges faced by young engineers today, and the column How to succeed at career and project migration with protégé Bill Thomas on how to make the most out of yourself and your project. Providing discussion and answers besides Greg McMillan and co-founder of the program Hunter Vegas (project engineering manager at Wunderlich-Malec) are resources Mark Darby (principal consultant at CMiD Solutions), Brian Hrankowsky (consultant engineer at a major pharmaceutical company), Michel Ruel (executive director, engineering practice at BBA Inc.), Leah Ruder (director of global project engineering at the Midwest Engineering Center of Emerson Automation Solutions), Nick Sands (ISA Fellow and Manufacturing Technology Fellow at DuPont), Bart Propst (process control leader for the Ascend Performance Materials Chocolate Bayou plant), Angela Valdes (automation manager of the Toronto office for SNC-Lavalin), and Daniel Warren (senior instrumentation/electrical specialist at D.M.W. Instrumentation Consulting Services, Ltd.).

About the Lead Author

Gregory K. McMillan, CAP, is a retired Senior Fellow from Solutia/Monsanto where he worked in engineering technology on process control improvement. Greg was also an affiliate professor for Washington University in Saint Louis. Greg is an ISA Fellow and received the ISA Kermit Fischer Environmental Award for pH control in 1991, the Control magazine Engineer of the Year award for the process industry in 1994, was inducted into the Control magazine Process Automation Hall of Fame in 2001, was honored by InTech magazine in 2003 as one of the most influential innovators in automation, and received the ISA Life Achievement Award in 2010.