Model-*less* multivariable control: A brief history (and possible future)

By Allan Kern, P.E.

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Introduction

Terms such as "model-less", "small-matrix" and "operational" do not, as yet, evoke the same excitement that accompanied the historic arrival of model-*based* predictive multivariable control (MPC) on the industry scene some 30 years ago. But that excitement is long gone and an overhaul of industry's multivariable control paradigm is long overdue. When it comes, as it must, to respond to the lessons of the last 30 years and to meet the needs of modern process plant operation, these terms may well emerge at the heart of the new lexicon.

In those heady days, when MPC was young, it seemed as though it might *solve* process control altogether, much like GPS technology, which emerged in the same era, would go on to *solve* navigation – all that remained was to improve the tools, which, in the case of GPS, has certainly happened. But MPC has been slow to improve in the face of (now) decades of relentless experience. The primary area of emphasis (better tools for step-testing, model identification, and model-performance monitoring) has been unable to substantially alter the counter-intuitive experience of MPC (that achieving high performance remains elusive, rather than reliable).

The road to understanding has been long, but today the big picture is taking shape, revealing why progress has been slow all along, where the path forward now leads, and how it all fits together with many lessons from historical process control experience (both single-loop and multivariable), thereby helping to confirm this view of history.

Model-less multivariable control (Figure 1)

The slow pace of progress has stemmed from industry's steadfast commitment to the original promise of MPC (to *solve* process control completely), coupled with at least two unanticipated *structural* limitations, which have been succinctly summarized as follows[2]:

- *The process disturbances we seek to control often alter the very models we employ to control them.*
- *Operational pre-caution takes priority over error-minimization performance criteria.*

These two observations, by themselves, go a long way towards explaining why the road has been rocky and where it must go from here: *Where models change and error-minimization is not the main performance priority, then detailed models become untenable and unnecessary.*

Many aspects of MPC practice itself tell us this. Developments such as robustness algorithms and move suppression techniques essentially serve to *ignore model detail* in favor of more reliable performance. Model details (precise steady-state gains) are also not needed to arrive at the correct optimization solution, which is usually well-known by the operating team in the first place – very often, model gains are "tuned" to get the desired optimizer result, not the other way around.

Many people are already aware of these limitations, but perhaps not of their deeper structural significance and how they have impacted many aspects of MPC practice, performance and progress.

And while people often express surprise at the idea of "model-less" multivariable control, because industry is accustomed to the terms "model-based" and "multivariable" (invariably) going together, we'll see that multivariable control can also be – in many ways always has been – model-less.

Small-Matrix (Figure 2)

Another idea whose time has come is *small-matrix* design practice, in which the multivariable controller matrix design includes primarily the variables and interactions (models) that are already utilized in existing operation to manage process constraints and optimize operation. Put another way, the job of a multivariable controller application is (can be defined as) to automate the way the operating team *already* manages and optimizes the process *manually* (in absence of, or prior to deployment of, an *automated* multivariable controller).

Small-matrix design practice results in a relative handful of variables and models, versus *hundreds* that typically result from traditional big-matrix design practice. All the extra models netted by big-matrix practice are thought to contribute to a more complete solution, but in practice they more often lead to well-known (but still poorly understood) "degraded" MPC performance. They also render the finished controller *much* larger and more difficult to own and operate.

MPC engineers nowadays often instinctively prune matrices in attempts to make controllers more operable, manageable and reliable, but few have realized that the sensible conclusion to this trend is small-matrix design practice, which utilizes existing proven operation as the matrix design basis in the first place.

History repeats itself (and necessity fosters invention)

A compelling observation is the parallel experience of modern multivariable control modeling and historical single-loop tuning. The two activities (tuning and modeling) are fundamentally the same (measuring process response in order to derive controller settings). In theory, both should be reliable one-time tasks (there are endless confident papers on the theory and practice). Yet, in practice, both activities remain characterized by under-performance and chronic rework.

This compels us to look for *common* root causes, which immediately points to MPC's structural limitations (above) and the realization that they would have (in hindsight, plainly have had) the same effect on single-loop practice. Moreover, this makes the way forward clear: If industry is to achieve more reliable multivariable *and* single-loop control performance, it will need a control method that addresses these root causes – that is more *robust* with regard to changing process gains and that delivers *operational* performance.

This line of thought is only pursued reluctantly, because it appears to give up on any remaining hope of *solving* process control altogether, and to further complicate a technology that already suffers from unwieldiness. But, in the event, promising initial discoveries have been made, revealing a solution with the potential to overcome past structural limitations *and* simplify practice.

The model-less multivariable control method (Figure 3)

Shaped and compelled by these experiences, a model-less multivariable control method (tagged "XMC™", patent-pending) has been developed that conceptually comprises three parts:

- A logic-based *directional* move solver – because it determines only move direction, it needs only *gain direction*, not detailed models
- Pre-engineered move rates – just like driving a car, speed is based on getting to the destination safely (operational performance, Figure 4), not on distance to go or on minimizing travel time (error-minimization)
- Rate-predictive control (RPC™, patent-pending, Figure 5) – a novel technique to taper moves predictively, so that controlled variables land reliably on constraint limits or optimization targets without overshoot or oscillation (also part of operational performance)

Notably, RPC™ is *inherently adaptive* to changes in process gain. For example, if process gain increases, then actual process response will increase, and RPC™ will taper the moves correspondingly sooner. Equally important, the same holds true for changes in the predefined move rate, so that move rates can be adjusted to achieve desired operational performance, without impacting control performance. Aside from forming a key part of the model-less method, this also gives industry perhaps its first truly inherently adaptive control algorithm! (The entire "self-tuning controller" era came and went, without ever hitting on this *inherently* adaptive method.)

The "secret sauce" of XMC™ is not its mathematical *tour de force* (that was MPC), but the creative combination of its three individually novel parts, plus key lessons from history.

History's full circle

In sizing up this resulting small-matrix model-less method, one is struck that it basically mimics (automates) the proven methods that operating teams have *always* used to manage process constraints and optimize process operation, even before process computers and automated multivariable controllers ever came along.

To wit, operating teams historically rely on a robust working knowledge of the process, with an appreciation for the dynamic nature of process behavior. They rely on proven variables to manage constraints and optimize economics, avoiding variables that, for one reason or another, have shown themselves to be unreliable, unworthwhile, unwanted or risky. They make moves in cautious steps that avoid overshoot or oscillation, which can cause or mask (dreaded) process instability.

Model-less multivariable control mimics these prior proven manual methods, thereby capturing the usual automation benefits of greater consistency, timeliness and reliability, plus the traditional multivariable control benefits of increased capacity, efficiency and quality. These benefits derive primarily from *closing* the multivariable constraint control and optimization loops, not necessarily from using models to do so.

Future prospects

A successful model-less multivariable control method would have far-reaching implications for industry, because it would simplify ownership at nearly every life-cycle stage, with many onerous steps and costs going away completely. It would provide the *agile and affordable* multivariable control tool that industry has always needed and expected to evolve long ago.

For example, a prototype XMC™ controller has been developed and deployed *natively* on an industry standard DCS platform. In place of a design project, the controller was designed in a single *meeting.*

Deployment was guided by a *routine* Management of Change (MoC) checklist and support is provided by *in-house* DCS engineers (Figure 6).

This experience raises the prospect of automated multivariable control becoming the *core-competency* it ultimately must be for the process industries, because multivariable constraint control and optimization is an inherent aspect, whether manual or automated, of essentially every process operation.

Perhaps multivariable control, with all its moving targets and non-linear risks, will never be *solved* as neatly as GPS. But at today's juncture there are many lessons from industry's hard-earned experience to take forward, to move multivariable control past the problematic performance plateau where it has been stalled for the last decade or more, and into the future.

Figures

- See following pages and corresponding slide numbers in powerpoint file

References

1. Take the path to model-less multivariable control, Control Magazine, December, 2015 http://www.controlglobal.com/articles/2015/take-the-path-to-model-less-multivariable-control/

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About the Author

Allan Kern is a Control Engineering Consultant with Lin & Associates, Inc., of Phoenix, Arizona, USA, where he is responsible for Advanced Process Control, including XMC™. He has 35 years of industrial process control experience and has authored numerous papers on a wide range of practical process automation solutions. He is the recipient of the International Society of Automation (ISA) 2015 Nels Tyring Award for his article "Multivariable control performance: the case for model-less multivariable control." He is the inventor and patent-holder for XMC™ model-less multivariable control method, and RPC™ rate-predictive control method. He has professional engineering licenses in Chemical Engineering and Control Systems Engineering and is a 1981 Chemical Engineering graduate of the University of Wyoming. He can be contacted at Kern@LinAndAssociates.com.

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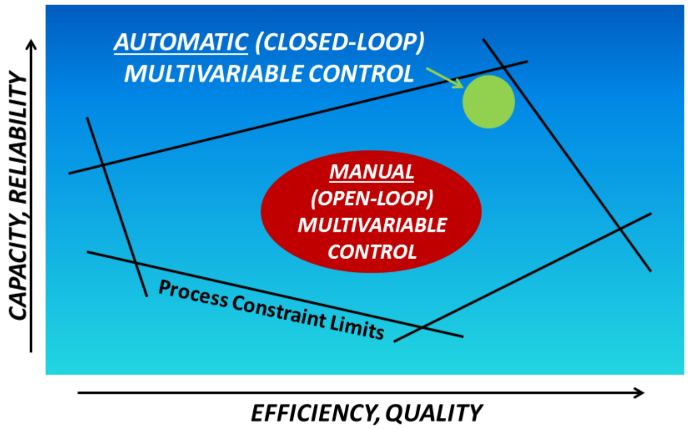

Figure 1. Model-less multivariable control mimics (automates) prior proven manual operation methods, thereby capturing the normal automation benefits of greater consistency and timeliness, plus the traditional multivariable control benefits of increased capacity, efficiency and quality. These benefits derive from reliably *closing* the constraint control and optimization loops, not necessarily from using models to do so.

Big Matrix Design Practice	Small Matrix Design Practice
Double-digit matrix dimensions, e.g. 20x50	Typically single-digit matrix dimensions, e.g. 6x8
Hundreds of variables and models. Large and complex to own and operate.	One or two *dozen* models. Intuitive to own and operate.
Based on identifying *all* process interactions. In operation, many prove unwanted for a variety of reasons.	Based on the variables and interactions used in existing operation to manage constraints and optimize the process.

Figure 2. Summary of small-matrix design practice versus traditional big-matrix practice.

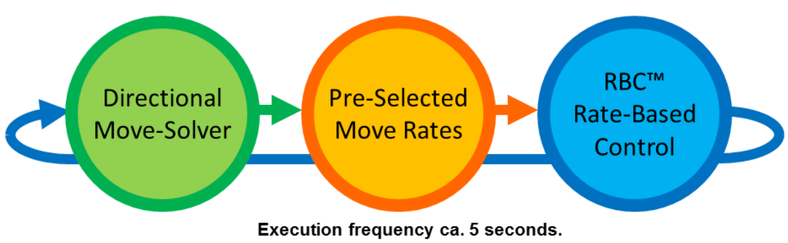

Figure 3. The model-less multivariable control method (tagged "XMC™") conceptually comprises three parts: a directional move solver, pre-selected move rates, and Rate-Predictive Control (RPC™), which is a novel technique to taper moves predictively.

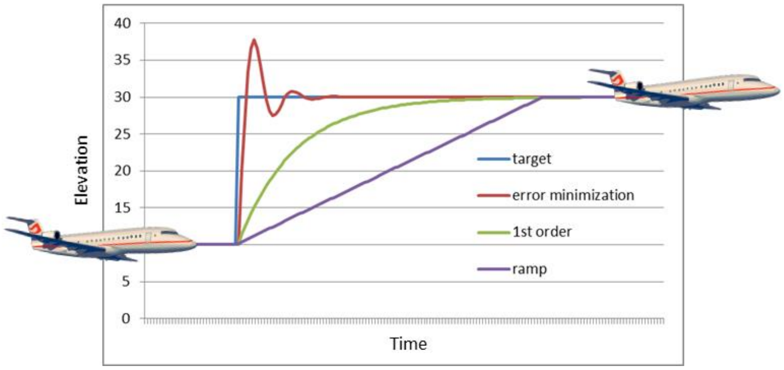

Figure 4. Industry's de facto control performance criteria is error-minimization, but industrial process operation (and other high-consequence activities, for example, piloting passenger jets) normally place higher emphasis on preserving process stability and operational pre-caution, which are represented by the 1st-order and ramp lines. Operational performance basically means pre-selected safe move rates, a first-order approach to targets, and minimal overshoot for both the direct control variables (DCVs) and indirect controlled variables (ICVs).

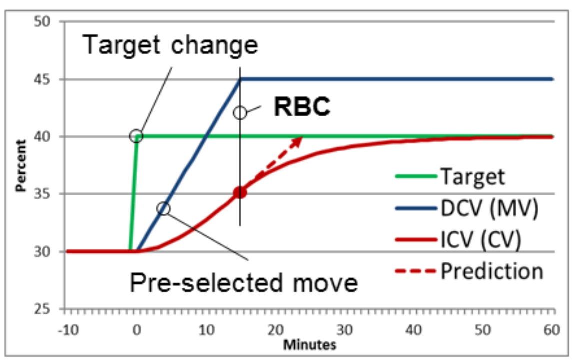

Figure 5. Rate-predictive control (RPC™) is a method to taper (reduce and halt) moves predictively. When the controlled variable prediction equals the target, the direct control variable (DCV) moves are halted. This results in the indirect control variable (ICV) ultimately settling on the constraint limit or optimization target without overshoot or oscillation (operational performance), based on first-order process response mathematics and dynamics. Moreover, it can be seen from this chart that RPC™ is inherently adaptive to changes in process gain and move rate – if they change, then the actual process response (ICV) will change, and RPC™ will taper the DCV moves correspondingly.

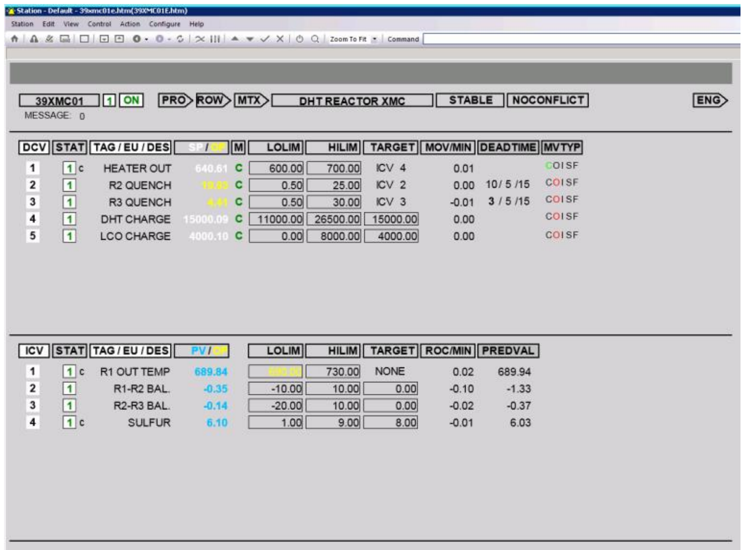

Figure 6: The model-less multivariable control technology is now in use at multiple industrial sites, having operated continuously and successfully (in some cases) for more than twelve months. The process control supervisor at one US refinery described their hydrotreater application experience this way: “Implementation was fairly routine, even though it was our first one. Operator acceptance has uptime have been excellent. The benefits we’ve seen are better sulfur control, increased product value (through optimized hydrogen uptake), smoother crude switches, and we’ve eliminated 90% of manual operator moves, freeing up time for other tasks and priorities.”