Operationally Challenged, Geometrically Solved

Geometric Process Control (GPC) combines the three key plant applications of process control, alarm management and the achievement of business objectives or quality control. It improves all three applications which were previously quite separate. Lacking a unifying mathematical basis, they came together only in the brains of individual process operators. Substantial economic and safety improvements result from this novel combination. The mathematical basis for the breakthrough is the use of n-dimensional geometry together with a coordinate transformation that makes it possible to see a multi-variable graph containing perhaps several hundred variables, such as temperatures, pressures, flows and product qualities, and thousands of different observations in a single picture.

One graph like this (Figure 1, below) can show all the contents of a spreadsheet of hundreds of columns and thousands of rows in a single picture.

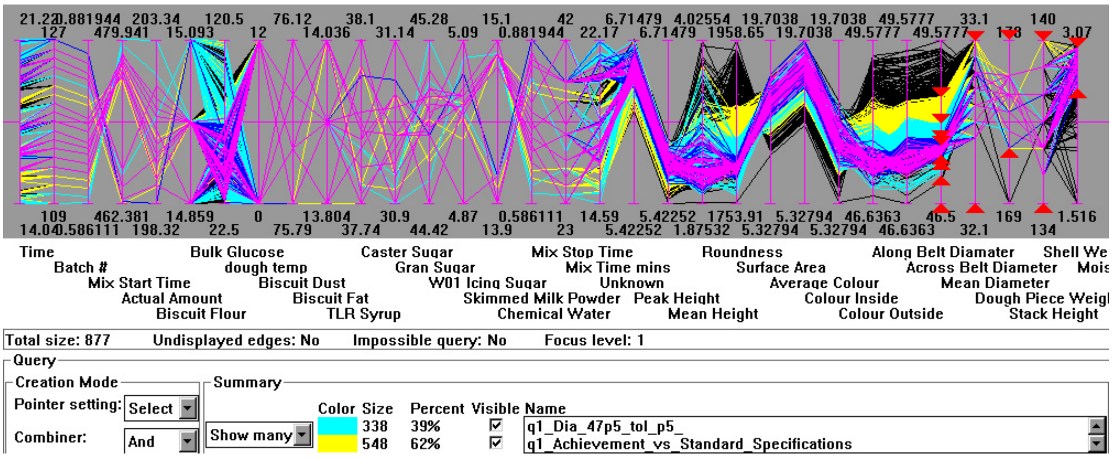

Figure 1

This may look complex but is really quite simple. Known as parallel co-ordinates (a name coined by Al Inselberg of IBM), each data point is represented by a polygonal line joining the values of the variables for that point. Until now, the world has been restricted to graphs that could show at most half-a-dozen variables. This has affected and limited understanding of multi-variable processes by forcing over-simplification. Behaviour could then be represented only in terms of the few variables that could be shown in a single graph.

Multivariable problems occur in every branch of engineering. A continuous chemical process is characterised by numerous flows, pressures, temperatures, concentrations and densities. Any sort of rolling mill operation has speeds, tensions and temperatures. And the discussion of the events of late August in North America and in London emphasizes the many variables involved in an electricity generation and transmission system.

Challenging Effects

These sorts of multivariable problems have two features that make them challenging: the effects of the different variables interact; and some of the variables are not under the engineer's direct control. Some measured variables are themselves dependent on others, and for many processes environmental variables such as air temperature, pressure or humidity are significant. Running such processes is not like cooking to a recipe; there is no one "right" set of values that can be set and will guarantee good results every time. Nor does keeping every controllable variable within permanent limits satisfy today's requirements for the best possible operation.

This is where Geometric Process Control comes in. Using the multivariable parallel co-ordinate display shown in Figure 1 to examine historical process or plant operating data, we can select the operating points that were satisfactory, in terms of product qualities, emissions, or whatever criteria we need to satisfy. GPC recognises that this set of satisfactory operating points defines a "shape" in the multi-dimensional space representing all the variables. We call this the Best Operating Zone (BOZ). Geometric Process Control then consists of keeping the operation in the BOZ. This is achieved in our product Curvaceous Process Modeller (CPM) by calculating limits on each variable that will keep it in the BOZ for the current values of all the other variables. That is, warning alarms have become dynamic and a means of control.

Figure 2 shows a typical CPM display, which of course uses parallel co-ordinates. The green lines show the outline of where the process currently needs to be. If the operating point is outside the BOZ, as shown by the magenta arrow on the leftmost axis in figure 2, CPM generates advice for how to get back inside it.

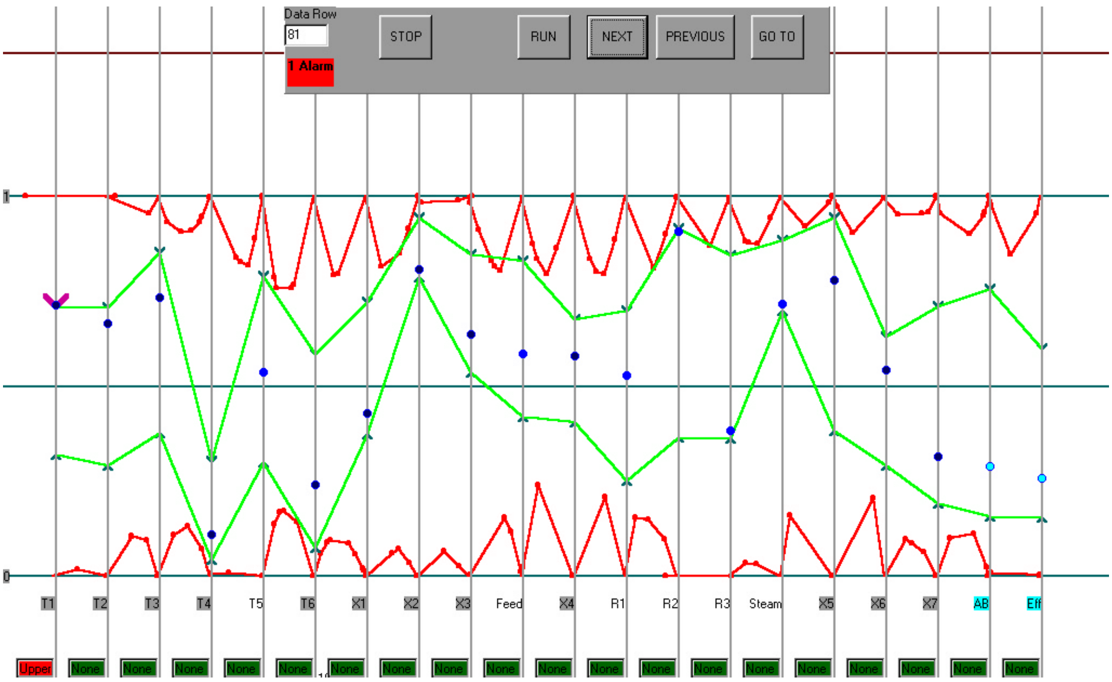

Figure 2

All of these quandaries are solved by geometry, which is possibly the way in which you solve the complex problems of everyday life - for instance, when you lift your hand to catch a ball. It is very unlikely that you actually formulate or solve the equations of motion to work out where to place your hand. It's much more likely that you use, unconsciously, something that's much more akin to the geometrical methods we are using.

GPC technology is very powerful and an enormous breakthrough. We use it primarily for process plants but there are many other multivariable problems around that we haven't yet addressed.

Process Plants

In process plants GPC is proving an enormous benefit. It saved our first customer, Ineos Chlor, significant money within weeks of going into use in the control room. It increased the performance of their process by 2%: this might not sound like very much but when you're dealing with hundreds of thousands of tonnes of product per year 2% is significant. It also made the process more reliable and consistent. GPC produced better values for the company to use as their alarm limits and helped eliminate false alarms.

The GPC display was found by the operators to be an improvement over the conventional display of alarms on a control panel. GPC also gave them much better product quality because it could work with predicted ranges - quality ranges predicted from the assessment of previous process measurements even though the lab quality measurements had not yet been made.

In addition, an application of GPC that we hadn't thought of, invented by one of the Ineos Chlor Engineers, cut start up time by a factor of six, which increased production time significantly.

Before GPC, start-up could often entail lots of "tweaking" of the process to get it just right. In plants that depend on laboratory analysis of samples there could be long delays waiting for confirmatory laboratory results before making further process alterations.

Using our method the delays are eliminated as we predict qualities accurately from the process variable values themselves and therefore cut the dependence on the laboratory. So the production time increases significantly which means processes are operating at their optimum for longer, fulfilling business needs and providing benefits, not least of which is cutting costs.

Curvaceous Software and Ineos Chlor (previously part of ICI Runcorn) joined forces in January 2001. Originally a nine-month trial, the contract was extended to 18 months and has now matured into a permanent installation.

GPC has been tried and tested on many processes and has proved very successful. Possible benefits are huge in a plant whether small or large.

Another advantage is that the methods are very simple to apply. Building a GPC model does not need advanced maths. The visual approach means users can apply their process knowledge directly without having to express it in (possibly doubtful) equations. Instead they can get straight on with using GPC and understanding their processes in greater depth.

It is possible to go directly from observation to the model in a few minutes. This means we can use this technique in small plants where they don't have control engineers or advanced mathematics or heavyweight statistical tools available to them.

A Multidimensional History

GPC technology uses the geometry of multiple-dimensions, of n-dimensional space. You're probably all familiar with the fact that Einstein's Theory of Relativity introduced the concept of four-dimensional space-time, which caused a huge amount of interest among the general public in the first part of the 20th century and started the Cubist movement.

Something that perhaps people aren't well aware of, those funny pictures that Picasso and his colleagues drew of people with holes in their heads were actually attempts to represent a person in four-dimensional space-time. Judge for yourself how successful that was. The String Theory being espoused by Stephen Hawkins and other leading physicists to unify quantum mechanics and relativity believes that we live in a 10- or maybe 25- dimensional space. Physics at the moment is pondering what the reality is of such a high dimensionality space.

Without worrying too much about the reality of whether we actually exist in multiple dimensions it turns out we can use the geometry of multiple dimensions very nicely to solve the everyday multi-variable problems that surround us.

Riemann was the first person to apply mathematics to multidimensional space in 1853 using algebraic and differential equations. However, these are difficult to use and understand which explains why, until now, his mathematical concepts have had little attention.

Case Study

The Problem

A manufacturing process suffered frequent and substantial disturbances to its feedstock causing it to make many undesirable by-products if several other variables were not quickly changed to compensate.
The product being made was sampled once every 12 hours but the analysis results were not available until five hours after that. The process was operated with experience-based judgement of what it was making extrapolated from process settings and hindsight.
Many different methods of improving operability, including an expert system rule base, had been tried on the plant during its lifetime, culminating in a steady improvement in its efficiency.
Our problem was that the GPC Alarm Advisory Algorithm, while giving very sophisticated operating advice on paper, needed a real process to prove the quality of the advice.

The Project

The project objectives included engineer assessment of the new alarms compared to their existing alarms: ddocumented operator usage of Human Machine Interaction and improved Key Performance Indicators through open-loop use of the Advisory Algorithm. Both product quality improvement and process operations improvement were expected.

The Solution

Historical operating data was examined using Curvaceous Visual Explorer (CVE) offline to understand past performance and identify several improvements. These included anomalies in the rules of the rule-based system that was being replaced.
A Best Operating Zone was selected and a GPC model built using CPM. The quality of Operator Alerts was investigated and false alerts reduced at the first attempt from 49% to less than 10%. The models were then run with real-time data by engineers for several weeks in order to build confidence in the quality of operating advice being generated before CPM was put into the control room for operator use.
What followed can safely be described as success. Ineos Chlor used GPC for several weeks in the control room in operator advisory mode. Not only did it gain a 2% improvement in the efficiency of their process in the first 3 weeks and reduce the start-up time by a factor of six, but other benefits were also readily apparent.
One of the main advantages of GPC is that it is so easy to use. Simple visual analysis for definition of their Best Operating Zone (BOZ) led to many valuable and unexpected discoveries. Quality and operations improvement was dramatic and is still continuing as the company's operators gain more confidence and implement more of the Advice.

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