

**Title:** A New Method for Defining and Managing Process Alarms and for Correcting Process Operation when an Alarm Occurs

**Author:** Robin Brooks PhD, Richard Thorpe BEng, John Wilson PhD, C.Eng.  
Curvaceous Software Limited, PO Box 43, Gerrards Cross, Bucks. SL9 8UX  
[Enquiries@curvaceous.com](mailto:Enquiries@curvaceous.com)

**Keywords:** Alarm Limits; Alarm Definitions; Alarm Management; Alarm Rationalisation; Geometric Process Control;

**Abstract:**

*A new mathematical treatment of alarms that considers them as multi-variable interactions between process variables has provided the first-ever method to calculate values for alarm limits. This has resulted in substantial reductions in false alarms and hence in alarm annunciation rates in field trials. It has also unified alarm management, process control and product quality control into a single mathematical framework so that operations improvement and hence economic benefits are obtained at the same time as increased process safety. Additionally an algorithm has been developed that advises what changes should be made to Manipulable process variables to clear an alarm.*

*The multi-variable Best Operating Zone at the heart of the method is derived from existing historical data using equation-free methods. It does not require a first-principles process model or an expensive series of process identification experiments. Integral with the method is a new format Process Operator Display that uses only existing variables to fully describe the multi-variable operating space. This combination of features makes it an affordable and maintainable solution for small plants and single items of equipment as well as for the largest plants. In many cases, it also provides the justification for the investments about to be made or already made in process historian systems.*

*Field Trials have been and are being conducted at IneosChlor and Mallinckrodt Chemicals, both in the UK, of the new Geometric Process Control (GPC) method for improving the quality of both process operations and product by providing Process Alarms and Alerts of much high quality than ever before.*

*The paper describes the methods used, including a simple visual method for Alarm Rationalisation that quickly delivers large sets of Consistent Alarm Limits, and the extension to full Alert Management with highlights from the Field Trials to indicate the overall effectiveness of the method in practice.*

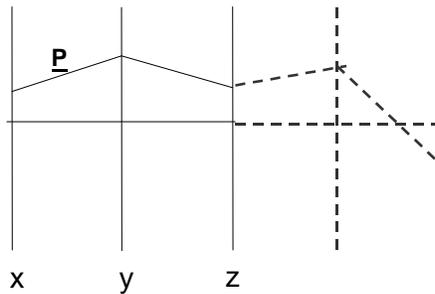
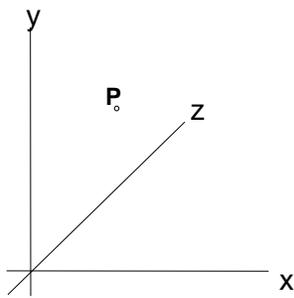
---

The state of Alarm Systems today is well described by Bransby and Jenkinson<sup>1</sup> and can be summarised as a focus on single variable alarming. There do not appear to be any generalised multi-variable alarming methods yet the multi-variable nature of alarms has been widely recognised as evidenced by the following quotation:

*“The purpose of Alarms is to maintain the plant within a safe operating envelope. A good alarm system helps the operator to correct potentially dangerous situations before the Emergency Shutdown System (ESD) is forced to intervene. This improves plant availability and economics. It also reduces the demand rate on the ESD and thus increases plant safety”<sup>2</sup>.*

An alarm occurs when a variable breaches an alarm limit so that the value at which the alarm limit is placed relative to the other variables is of considerable importance if a set of alarm limits are to define a safe operating envelope. The implication is that alarm limit values should be related to each other but today’s methods of setting alarm limits are primarily single-variable and empirical. There has been no general method available to calculate values for alarm limits either in single-variable or multi-variable cases and this is the root cause of the poor performance and poor regard in which operators hold alarm systems today.

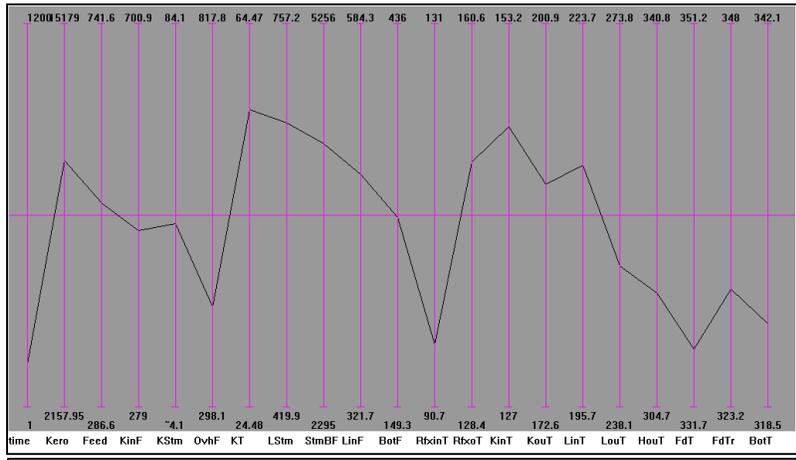
An operating envelope is of necessity a multi-variable or multi-dimensional envelope that



would be difficult to synthesise but can be defined instead by the set of multi-dimensional process operating points that it contains. Each operating point is simply the set of values of all of the process variables and can be written as  $(x_1, x_2, x_3, \dots, x_n)$  implying that a multi-

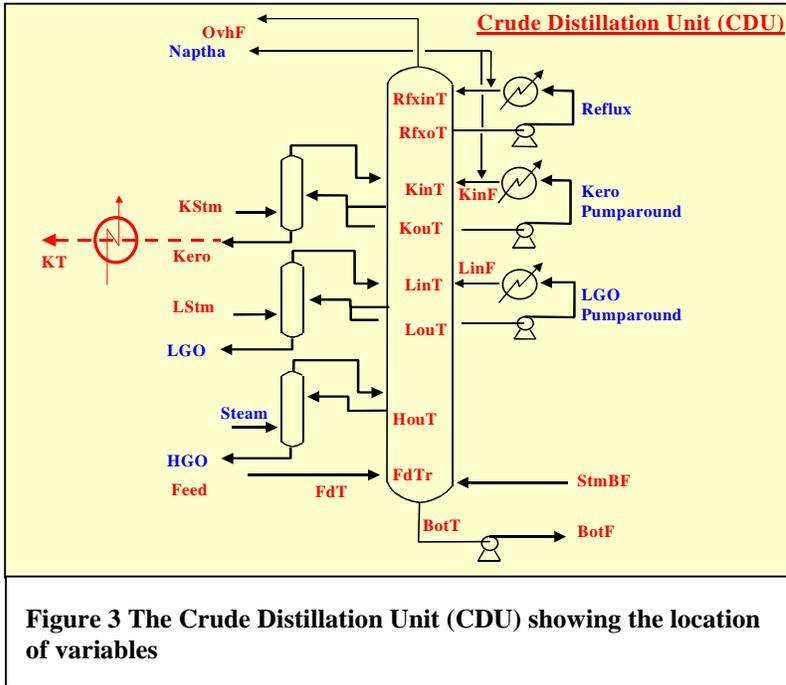
**Figure 1 The Parallel Coordinate Transformation**

dimensional visualisation method is required for ease of use. Inselberg's parallel coordinate transformation<sup>3</sup> provides a mathematically sound visualisation method that is capable of representing all needed aspects of n-dimensional geometry. It transforms the n-dimensional orthogonal space described by Riemann into a format that is easily visualised yet mathematically sound. In Inselberg's transformation points transform into polygonal lines as can be seen in Figure 1 where the point P in orthogonal 3-D space has transformed into the polygonal line P in parallel space.



**Figure 2 A 25-D graph showing one point**

Figure 2 shows an example of a single operating point for the Crude Distillation Column of Figure 3 that will be used as the example in this paper. It is a 25-dimensional graph with only one point plotted. Putting many more points onto the graph, in this case 1183



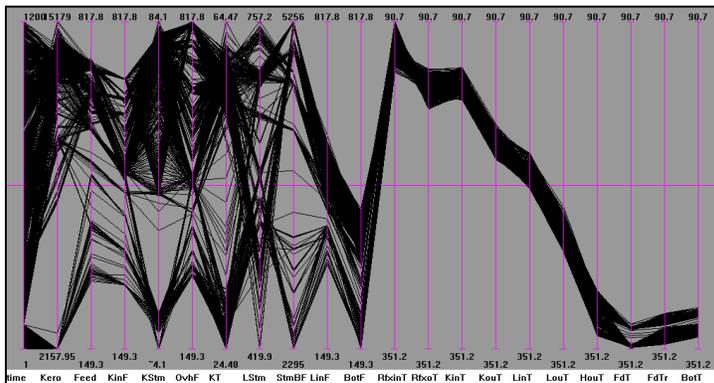
**Figure 3 The Crude Distillation Unit (CDU) showing the location of variables**

points representing nearly 2 months of operation sampled at hourly intervals gives the graph of Figure 4. A considerable advantage of the parallel coordinate transformation is that a layman can easily understand the graphical representation without the need for mathematical knowledge.

We might in some circumstances use the envelope of all the points in Figure 4 as the envelope of desired operation but usually

have some choice criteria to apply first. In this example there were concerns about the maximum tube wall temperatures in the fired heater, which translated into maximum transfer temperatures (FdT) of 345 degrees or 350 degrees.

These two regimes are shown coloured blue and yellow respectively in Figure 5 to show how two criteria applied on one variable (FdT) will select different usable ranges on other variables, for instance KinF, BotF, LStm and KinT, which give us immediately high-high and low-low alarm limit values for all variables. *These alarm limit values are all consistent with the one objective criteria of maximum tube temperature and thus are also consistent with each other so they are better alarm limits than the individually set high-high and low-low alarm limits in use today. They are probably not very different to those in use already for a plant with one mode of operation that has been very diligent in repeatedly revising its alarm limits and so has iterated towards a consistent set.*



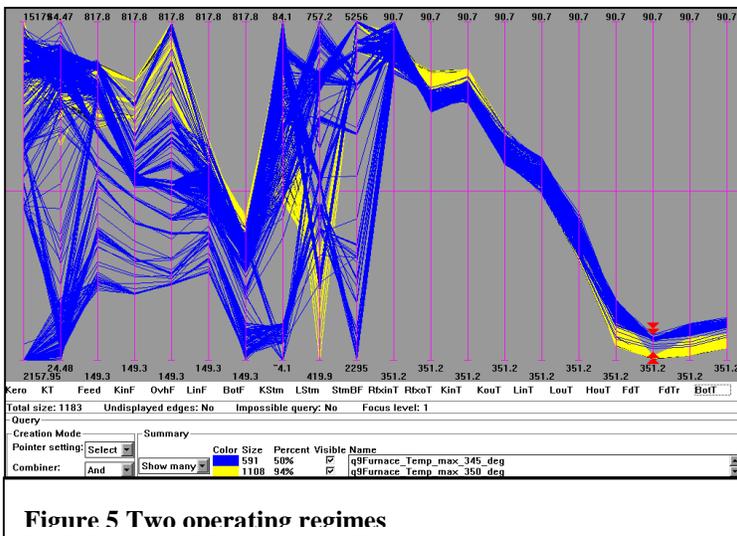
**Figure 4 The same graph with over 1000 points representing 3 months of operation**

There could of course be many criteria to be satisfied

in which case the envelope is in general reduced in size by the application of each successive criterion.

Note that the selection of the acceptable dataset to define the envelope is the whole of the model-building process. A process engineer in one of the trials commented that he could build and install a new model in half-an-hour.

A little thought will reveal that the values of the high-high/low-low alarm limits on each variables axis creates a multi-dimensional rectangular box or hypercube which emphasises that fixed alarm limits must be asserting non-existent independence between variables. Interactions between variables define a non-rectangular operating zone envelope inside and thus of less 'volume' than the enclosing hypercube. It is thus necessary to consider what happens between the axes of the parallel coordinate plot in order to understand the actual shape of the non-rectangular operating zone.



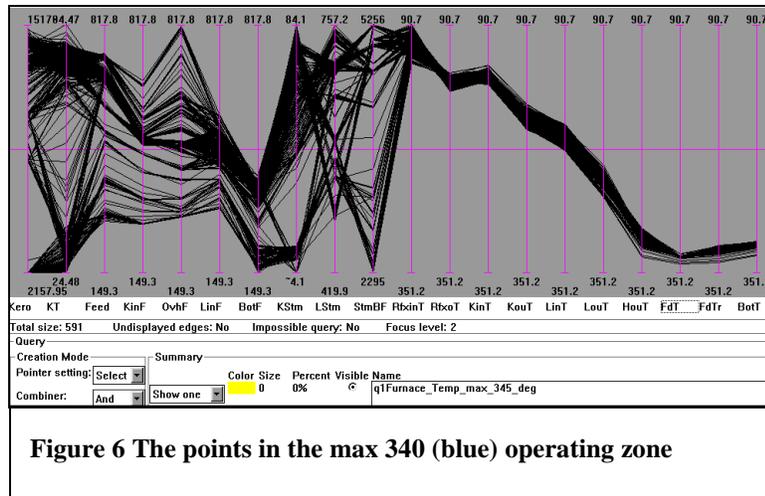
**Figure 5 Two operating regimes**

Suppose in Figure 5 the blue (FdT<345 degrees) operating zone was chosen. Isolating the blue points gives Figure 6. We can thus say that it is necessary to stay simultaneously inside all the variable ranges identified by the points in Figure 6 in order to always meet the objective FdT<345.

Alternatively, if we take the envelope of the points in Figure 6, any operating point has to be an interior point of

the envelope in order to meet the objective FdT<345. Geometrical methods can be used to construct the envelope and can also determine whether the current operating point is an interior point or an exterior point. However, as soon as a value is fixed for any one variable the affect is to identify reduced ranges on all the other variables within which values of those variables must lie in order for the point to remain wholly within the envelope.

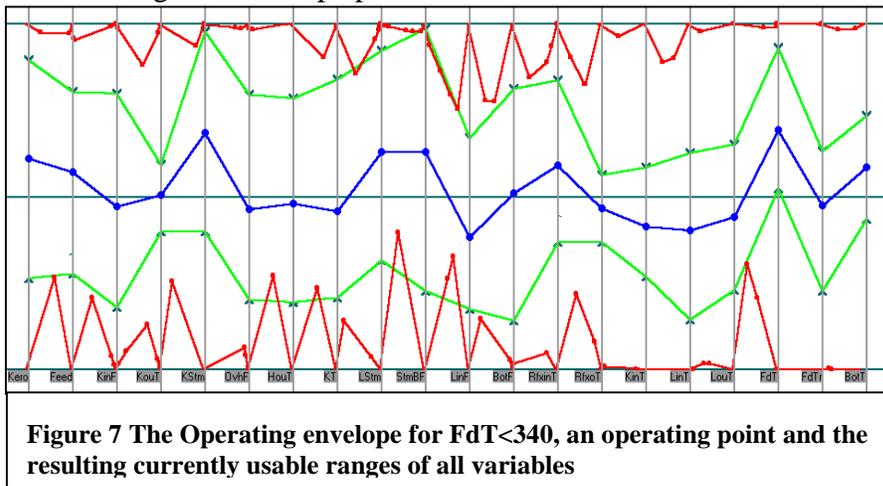
The result of this construction is shown in Figure 7 in the way that it is displayed to the process operator. The current process operating point is shown by the set of blue dots connected to



**Figure 6 The points in the max 340 (blue) operating zone**

form a blue polygonal line. The red outlines are the projections of the envelope of the points from Figure 6 scaled for maximum resolution. The green values on each variable represent the reduced ranges or available ranges that must be observed around the current operating point in order to be an interior point of the red envelope and thus not in alarm. The points where the red envelope meets the vertical axes are the high-high and low-low alarm levels.

The green envelope changes shape as the process operating point moves and it is the role of process control (whether manual control or model based control) to keep the process inside the green envelope at all times and thus achieve the objective by which the red envelope was chosen. Reversing this, we can see that if any variables value were to be outside the green envelope process control would have failed in the task of which it was



**Figure 7 The Operating envelope for FdT<340, an operating point and the resulting currently usable ranges of all variables**

previously capable. Thus the green values on each variable represent the earliest value at which one can confidently say that a problem is developing and are where we define and announce an Alert or

High/Low alarm. Since the high/low alarm levels are the ends of the available range on each variable due to the values of the other variables in relation to the red envelope, when the process moves the high-low alarm levels (and the green envelope joining them) move.

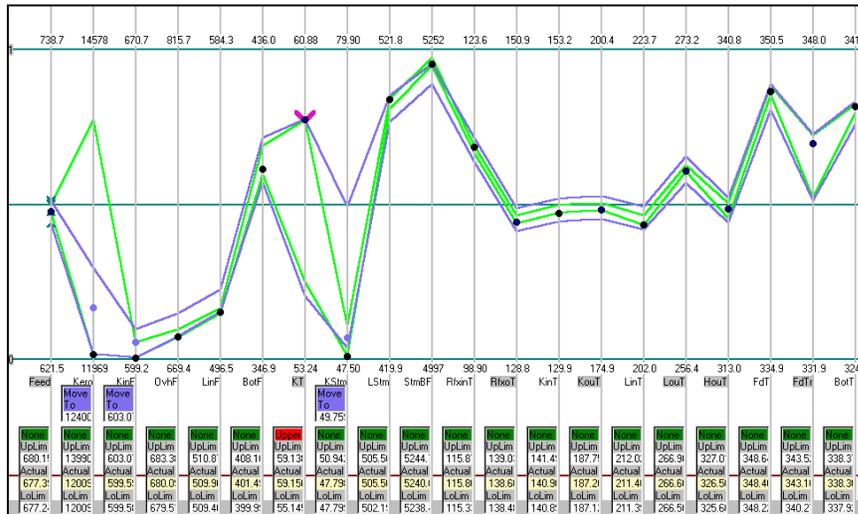
Industry has been accustomed to leave the High/Low alarm limits fixed for want of any way to calculate how to move them. This accounted for the very high proportion of false alarms, which both raised the annunciation rate and devalued all alarms for the operator. This led in many plants to High/Low alarms set so wide apart that they almost never annunciated, which is almost the same thing as having no High/Low alarms and depending on operator vigilance and HighHigh/LowLow alarms. The advantage of having good High/Low alarms is that the operator is asked to intervene when the maximum time is available for him to find a remedy and before the process has developed too much momentum in its movement. Geometric Process Control puts high/low alarm levels at the heart of process control.

These Alarms and Alerts are particularly good because of the subtlety of the variable inter-relationships captured by the red envelope. This was evidenced during the IneosChlor Field Trial by a single standing Alert on a reactor exit temperature. The value was above the green limit but below the red so was well within what would previously have been considered a normal range. Investigation revealed that reactor coolant level, a

variable not measured by the computer, was lower than usual so removing less heat and causing a higher than usual outlet temperature. In other words, the Alarm detected was not simply a high value of one variable in isolation but was a deviation from the normal heat balance relationship between several variables. The ability to detect this type of multi-variable alarm without the engineer having had to think of providing for the possibility is extremely powerful and reassuring in terms of additional plant safety.

Once an Alarm or Alert has occurred geometry can be used again to generate corrective changes to the Manipulable variables. We use the term ‘manipulable variables’ to mean those variables, such as flows (or, in some cases, set points of regulatory controllers), that can be changed directly. A density, for instance, may be measured online but cannot be changed directly. Effectively we find changes to the Manipulable variables that would cause the shape of the green envelope to change such that the maximum number of Alerted variable values are included in the re-shaped envelope so minimising the total number of alarms. In practice it has been found that following the advice given over a few time steps fairly quickly brings the process back to a normal or no-alarms state.

Figure 8 shows an example of the process operating advice given with the red envelope not displayed at the request of process operators since it does not change and its omission increases the clarity of the display. There is one Alert (a High alarm) on variable KT, which is not directly manipulable. Increasing the Kero product flow rate, the kerosene return from the stripping column to the main column KinF and the steam flow to the kerosene stripping column KStm will change the shape of the green envelope to that of



the blue envelope which is sufficient to clear the alarm on KT.

This is very sophisticated advice to be generated by an algorithm. It appears at least comparable to that generated by rule-based systems in the subject categories of ‘Knowledge Engineering’ and ‘Computational

**Figure 8 The geometric algorithm generates sophisticated advice involving moves of three variables to correct one alarm**

Intelligence’ but without the sometimes considerable cost of building and maintaining a rule-base.

The desire to prove the quality of the alarms and of the advice on a real process was the motivator for the two field trials conducted at Ineos Chlor, Runcorn, UK and

Mallinckrodt Chemicals, Staveley, UK. For these early trials it was decided to run in open-loop operator guidance mode. The first trial has completed with considerable success, the results have been publicised<sup>4</sup> and a permanent installation is commissioning now, the second trial is still in progress but results to date are fully supportive of the first trial results.

The results of the first trial included an assessment of alarm quality by comparing alarms generated using alarm limits set using the best experience and knowledge of the plants engineers with alarm limits generated using the methods described in this paper. The objective in both cases was to produce product within specifications as measured by subsequent laboratory analyses. Alarms were retrospectively rated true or false depending on the result of the laboratory analysis when it was received some hours later. Alarms raised with the traditionally set alarm limits were false 49% of the time whereas those raised by the new method were false only 10% of the time. The 10% has since been further reduced by improved choice of variables in the envelope.

Reducing the total number of alarms annunciated by 39% also reduced the Annunciation Rate, defined as the average number of alarms annunciated per minute, in a similar proportion.

Warning Alarms (Hi-Lo Alarms) successfully advised operators where to operate the process. The principle is not to only react to alarms when they happen, but to try to keep the process well inside the green envelope with some up and down leeway on each variable.

It is possible when designing alarm systems to overlook the fact that *any alarm system is only as good as the operator's confidence in it*. An essential feature of GPC is that operators appreciate the rationale of the alarms raised.

The operators were asked to record their acceptance or rejection of the advice generated (through a form on the display). The conclusion was that the operators generally accepted the advice. It was interesting that advice could be generated that made physical sense to those who knew the process without explicitly representing any physical/chemical relationships in the model. It seems that *the geometric model does capture the essential relationships among the variables*.

## **Acknowledgements**

The work described in this paper was the winner of the European Process Safety Centre (EPSC) Award 2003 for the biggest single contribution to increased process safety.  
[www.epsc.org](http://www.epsc.org)

## References

---

<sup>1</sup> Bransby, M.L. and Jenkinson, J. The Management of Alarm Systems, HSE Books 1998 ISBN 0-7176-1515-4. [www.open.gov.uk/hse/hsehome.htm](http://www.open.gov.uk/hse/hsehome.htm)

<sup>2</sup> Alarm Systems. A Guide to Design, Management and Procurement. EEMUA Publication No. 191 : 1999 London. ISBN 086931 076 0 [www.eemua.co.uk](http://www.eemua.co.uk)

<sup>3</sup> Inselberg, A. and Dimsdale, B. Parallel Coordinates - A Tool for Visualising Multivariate Relations. Human-Machine Interactive Systems Ed A. Klinger. Plenum Publishing Corp. 1991.

<sup>4</sup> D.Armstrong PhD, M.Tyrrell BSc, S.Casey BSc, Ineos Chlor Ltd. R.Brooks PhD, R.Thorpe BEng, J.Wilson PhD, Curvaceous Software Limited. First Experiences at Ineos Chlor Ltd. with GPC for Product Quality and Process Operations Improvement. AspenWorld November 2002. Also available from [www.curvaceous.com](http://www.curvaceous.com)