Defeating An Old Adversary… Cement Kiln Balls

For reasons not well understood kilns – pulp, cement, etc. – form balls. Although creative solutions, including use of the 04 gauge shotgun kept in a certain pulp mill's control room, have been devised for their elimination such balls frequently grow without bound. In addition to product degradation, as material at the core of a ball is less thoroughly processed than that on its exterior, this growth generally leads to problematically sized objects (e.g., up to a meter or more in diameter) which force kiln shutdown. Beyond rework of product caught in the kiln when it became choked by large objects – which can also damage refractory material in the cement case – this drives a throughput penalty from frequent start-ups and shutdowns that can be the operational bane of a plant's existence. Hence, although blasting pulp balls out of existence can provide diversion for the control room staff and viable klinker is generally made (albeit at high cost) in cement kilns that are cycled up and down, prevention is a far superior solution. Unsurprisingly, this proved easier said than done at a major cement manufacturer's facility where two large kilns were freakishly affected -–winter and summer, without apparent pattern or reason – by unexpected ball formation which considerably restricted output.

Fortunately both kilns, although built at different times and not identically configured, were well instrumented and virtually all aspects of their operation could be tracked by flat file extract from an InfoPlus.21® Database updated in real-time. So, given that instrumentation was complete and information, including apparent ball size graded on a 0-3 scale (representing no balls, balls up to six inches in diameter, balls of 6-12 inches, and balls greater than a foot in size, respectively) readily available, what really became necessary was comprehension of the relationship between process parameters as well as kiln conditions and ball size. The latter, however, was no simple matter as over 40 thermal, mechanical, and chemical variables, all believed salient, were under measurement in addition to ball size as elements of a problem that had, due to limitations in conventional means to display and understand data, stumped the cement industry for decades.

Available Mathematics

Consider a situation of 44 variables, as was the case for each of the cement kilns in question. Conventionally, and by the precepts of Descartes – orthogonal space, defined by two (Cartesian Coordinate) or at most three variables simultaneously – one can see at most two or three aspects of a problem (such as ball size versus kiln rotational speed and coke feed) simultaneously. Hence, for a mathematically simplistic analysis that did not consider interactions among the variables driving kiln behavior, one could see all the information contained within data describing kiln behavior in 43 separate two dimensional or 22 individual three variable plots of kiln variables versus ball size. Interactions expand this number enormously, with over 900 two-dimensional plots necessary to faithfully represent kiln behavior in that instance. Unsurprisingly, this graphical status quo of understanding why kilns generate balls had, like all numerical approaches to the problem, failed to produce a solution.

A Better Way

During the latter 1980s and early 1990s IBM, faced with similar analytical frustrations in their own operations, patented an innovative means to display and analyze multi-dimensional data that is only now reaching public domain in a wide variety of applications. Consider presentation of the kiln database in parallel coordinates as suggested on the right hand side of Figure One, where coordinate axes do not intersect and a single observation plots as a value on each variable axis (these are laid out vertically, and in parallel) connected by line segments.

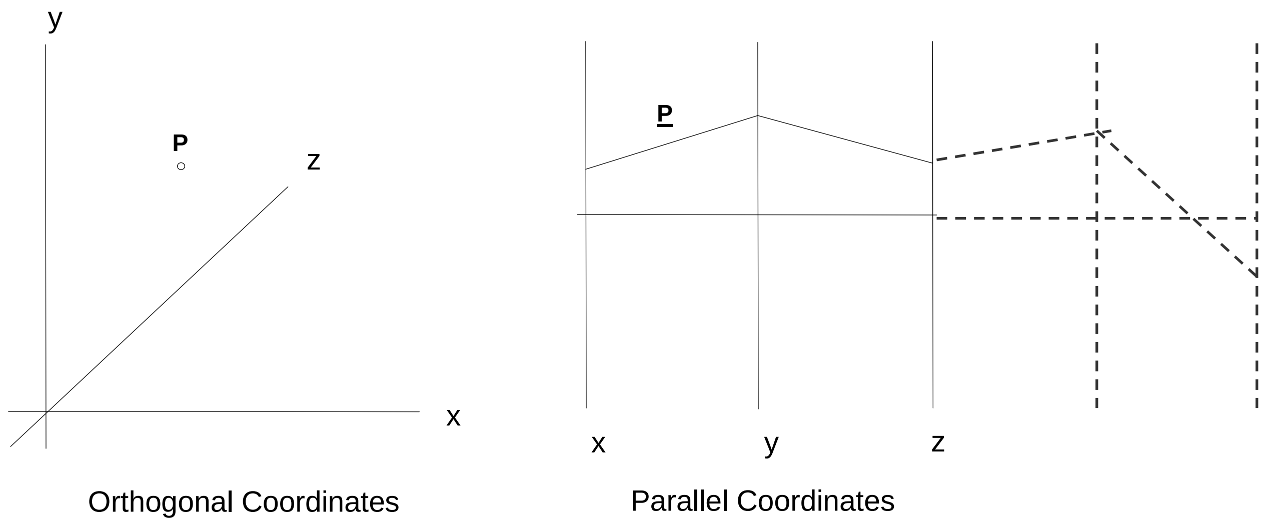

Figure 1: The Parallel Coordinate Transform.

For the kiln dataset, with 44 variables involved (starting with a grading of ball size) this stretches across two pages covering thermal and mechanical measurements followed by chemical characteristics of kiln behavior as diagrammed in Figures 2a and 2b, respectively.

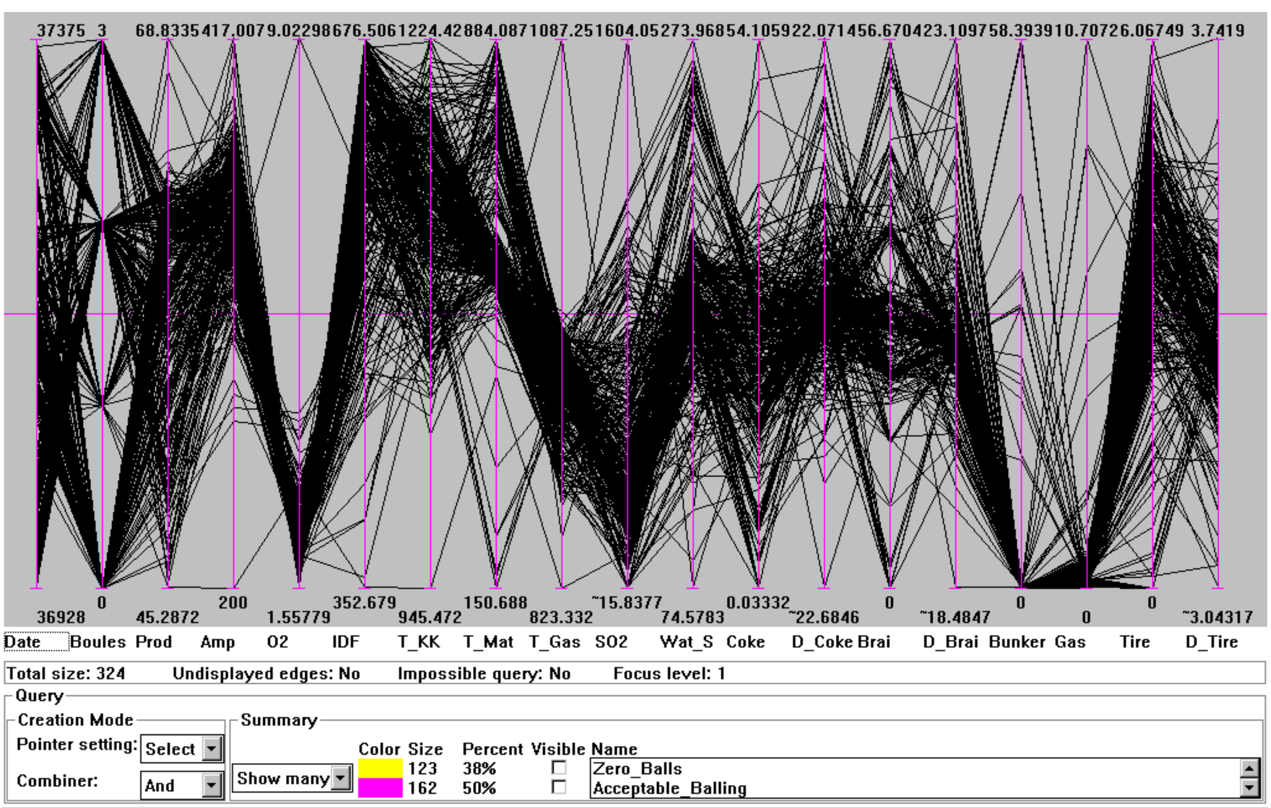

Figure 2a: Grading of Balls (Boules) produced on the second axis from left followed by kiln thermal and mechanical variables portrayed on parallel coordinate axes.

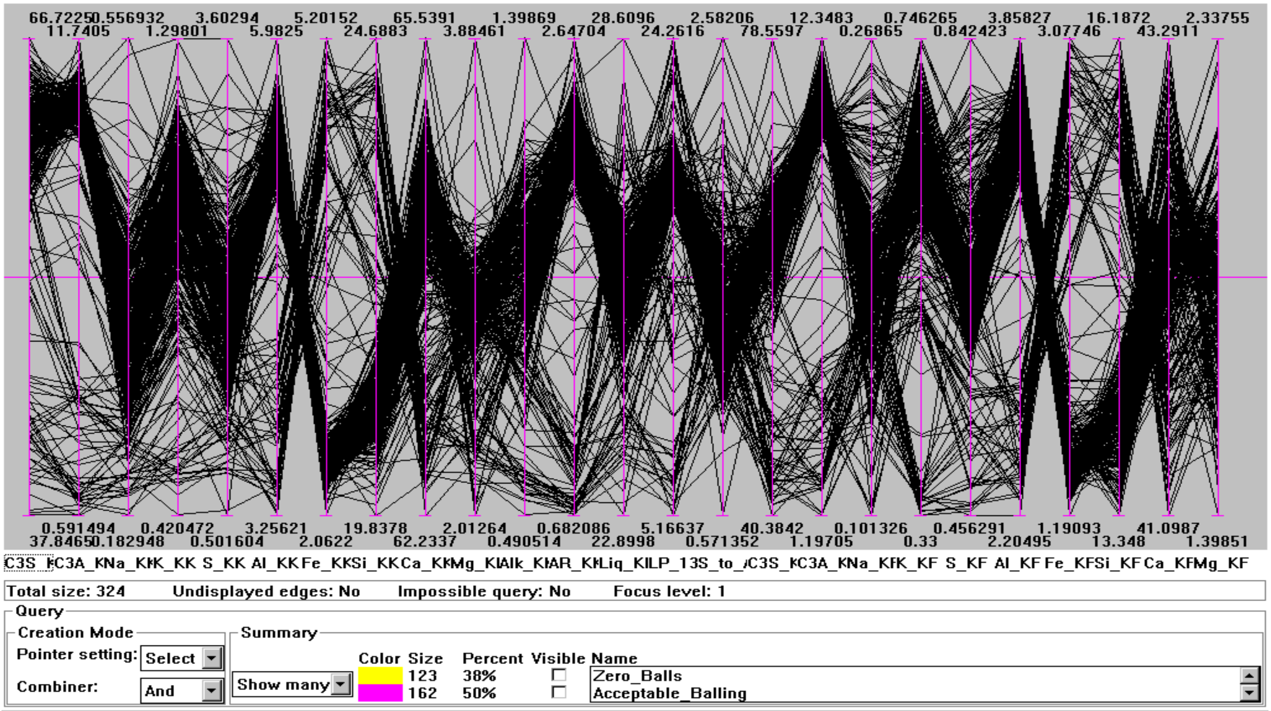

Figure 2b: Corresponding chemical conditions for kiln data of Figure 2a.

Hence, although they appear as a tangle of black lines, with each line representing related measurements for thermal, mechanical, and chemical variables preceded by the ball size they create, one can actually see all variables simultaneously. Consequently, using the visual query capabilities of a system known as Curvaceous Visual Explorer (CVE) – which was engaged to conduct data analysis and produced all graphics within this case study – we can highlight ball sizes in manufacturing data by color to discern origins of the problem. This is done in yellow (no balling), fuchsia (acceptable balls up to 12" in size), and blue (for unacceptably sized balls greater than a foot in their largest dimension), yielding Figures 3a and 3b.

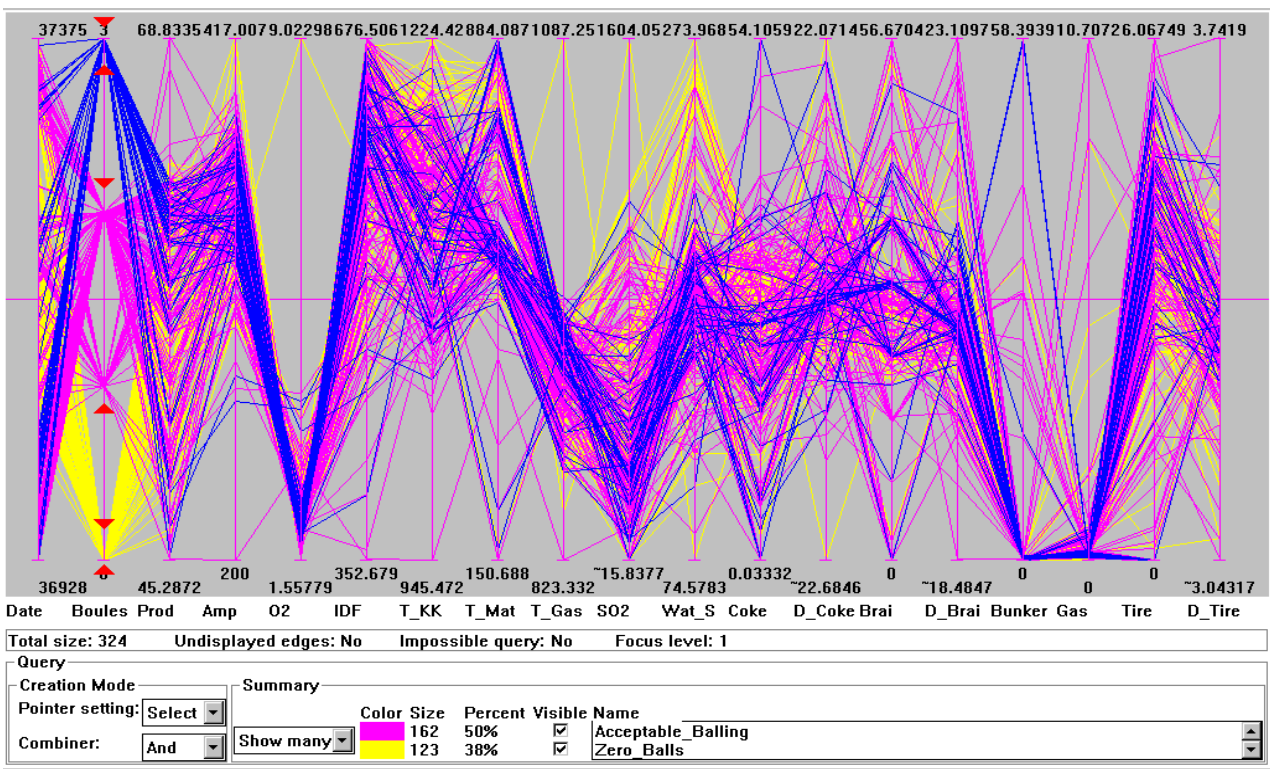

Figure 3a: Thermal and mechanical conditions associated with zero (yellow), acceptable (fuchsia), and severe (blue) balling.

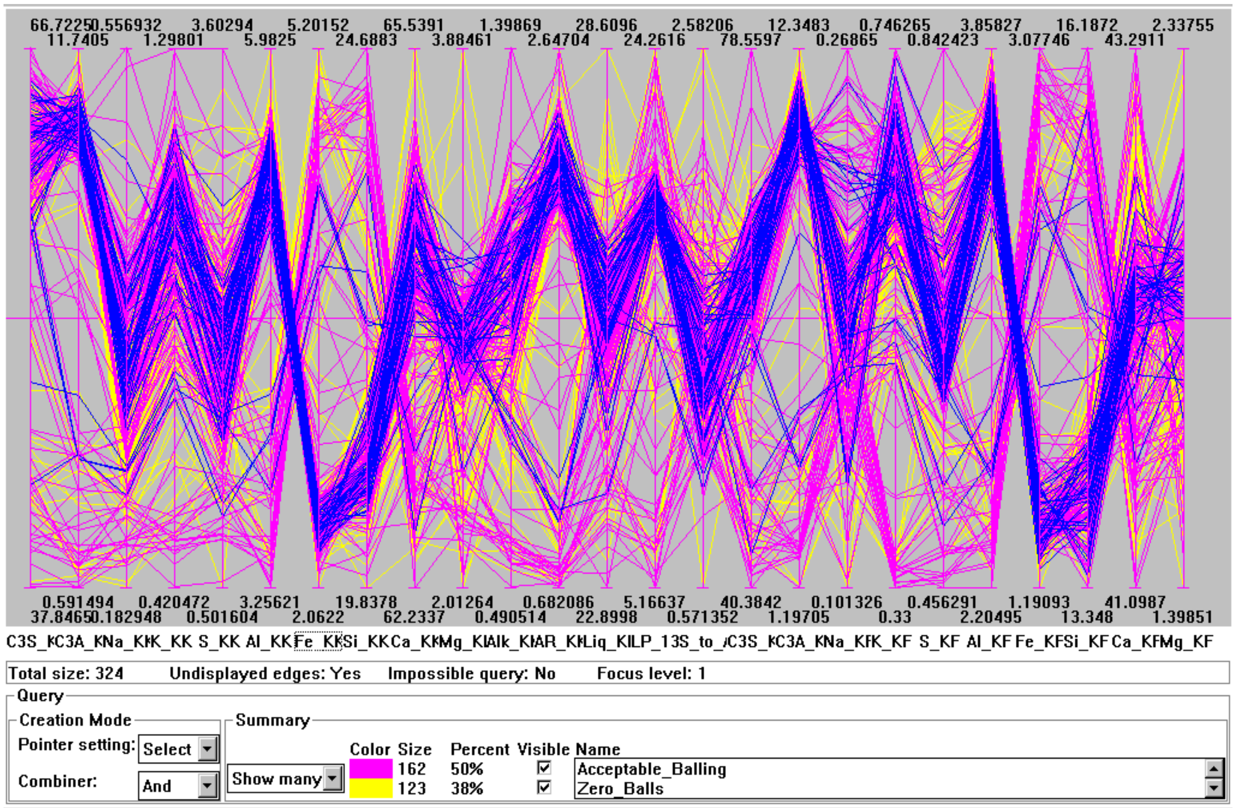

Figure 3b: Kiln chemical conditions corresponding to zero, acceptable, and severe ball formation.

Finding the Answer

Looking closely at Figures 3a and 3b, where unacceptable balling conditions (the blue lines) have been plotted atop acceptable balling (the fuchsia lines), which in turn are plotted over zero (yellow) balling conditions one is immediately struck by two observations:

1. With the exception of upper reaches in Wat_S the range of non-balling conditions (the yellow lines) where adverse balling results (the blue lines) do not also occur lie near extremes of where individual variables have been operated, and particularly so for chemical variables.
2. In general, conditions which do not create balls are co-incident with those that do.

Although one could attempt to control a kiln (with difficulty, no doubt) at extremes of conventionally viable operating ranges this second observation is particularly unsettling, as it typically corresponds to one of two possible situations:

1. There are one or more missing, often known as “lurking,” variables of which we have no knowledge also driving the creation or suppression of cement kiln balls.
2. The operational variables driving thermal and chemical processes within a kiln are highly interactive in their influence on the overall calcination process (and hence balling therein) with variable levels themselves less significant than relative variable levels and, in all likelihood, rates of change as well.

As rotary cement kilns are known to be complex chemical reactors prone to internal cycles and consequent instability the second scenario seemed far more likely to the industry team conducting this analysis. Now, however, to reach an analysis that team was challenged with capturing salient rate of change variables likely to be triggering the creation of kiln balls.

Calcination is a thermally driven process, with burning zone combustion for the kilns in question being fueled by varying amounts of natural gas, fuel oil, coke, brai (pitch), and automobile tires although the latter three, being least expensive (in actuality, cement plants are frequently paid to burn tires) were the predominant fuels used. Hence the team working on this problem, in what amounted to a visual brain-storming session powered by the multi-dimensional facilities of CVE and combined experience of many individuals, reasoned that adding the rate of change in major fuels would capture the missing information. This turned out to be correct, as adding axes for D_Coke, D_Brai, and D_Tire, positioned next to the axes for Coke, Brai, and Tires, then drawing flow queries yielded the rather interesting result of Figure Four.

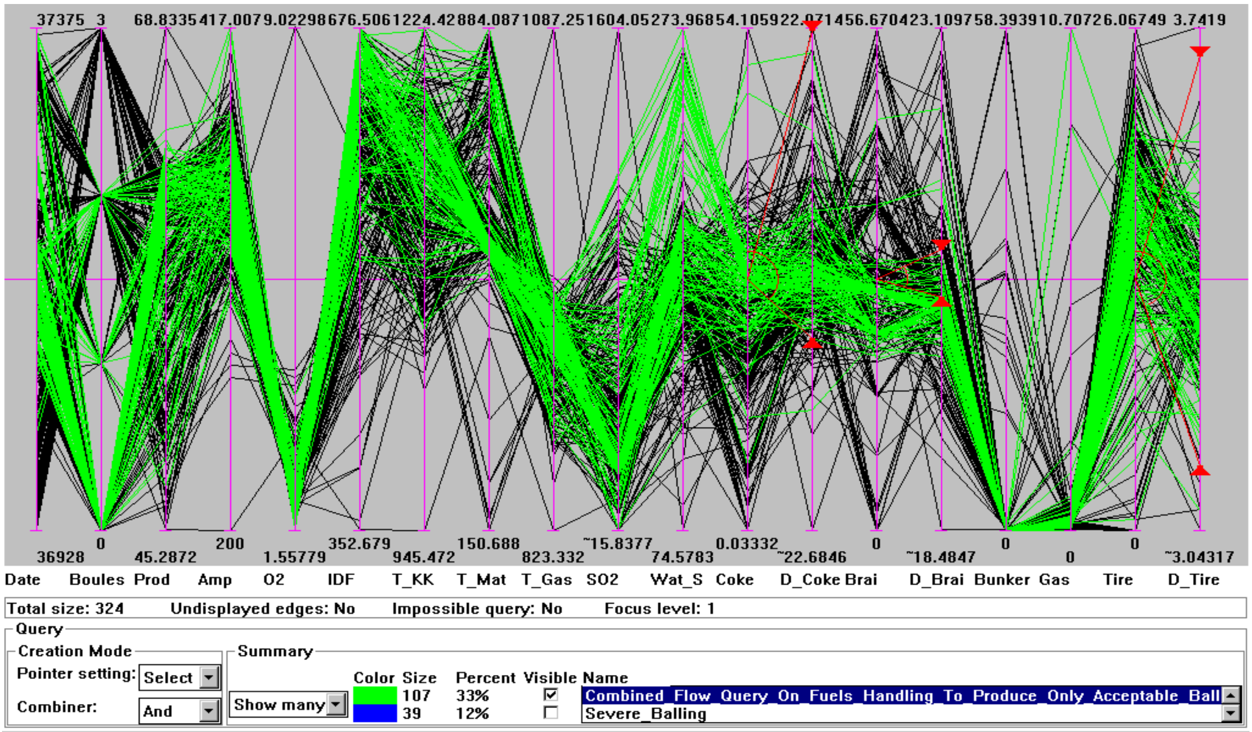

Figure Four: Combined flow query on major fuels handling to isolate only acceptable balling conditions.

Note that by restricting, as illustrated by the green query lines of Figure Four, the range and rate of change for Coke, Brai, and Tires unacceptable balling conditions – corresponding to the creation of balls greater than one foot in diameter – can be entirely avoided. Hence, by “not throwing the fuels around” one can engineer a consistent Best Operating Zone where chemical conditions favoring unchecked ball formation (which are likely always to be present in cement kilns) are never provoked into action. More to the point, by letting that sleeping dog lie the kilns in question set production records during the summer following this analysis.