FAQ – Frequently Asked Questions

(and some not so frequent)

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1. Why is Ultramax so universally applicable with the same Software?

It turns out that man-made systems (and many natural ones) have a response pattern which is amazingly widespread, captured in the modeling structure within UMAX. And further, UMAX is applied to operations where there is a sufficient amount of data to quantify those patterns; as it happens frequently in production / manufacturing.

This particular pattern is "macro continuity": small changes in inputs create at most small changes in outputs; medium changes in inputs create at most medium changes in outputs – a pattern required for the control of the response, the operations. In other words, the response is "gradual and smooth" -- even if it is a series of small jumps or micro-discontinuities. The major exception is the point at which the system breaks down, but we take good care to exercise control away from that limit; an aspect also managed by UMAX to yield sufficient reliability when the limit is known.

Some characteristics of the models created within UMAX are:

- Using Bayesian statistics, small amounts of operating data provides rudimentary but useful understanding of the direction for improved adjustments, way before other analytical technologies are even capable of processing the data.
- Since the objective is optimization – not prediction at all possible conditions – the response in only a small multivariable region of inputs needs to be accurate: the region around the optimum (or the best known operating area in the sequential optimization). Thus UMAX models are not distorted by fitting useless data far from the optimal region. These locally-accurate, goal-oriented models are created with a very unique and proprietary modeling approach.
- These models are refined when each new set of operating data becomes available, and when a new set of (forced) uncontrolled conditions occur.

And all the above features are totally automated, not requiring statistical / mathematical knowledge on the part of the user. In fact, UMAX can run closed loop for autonomous optimization (until detecting an abnormal pattern of behavior).

2. Can I use Ultramax to Reduce Energy Consumption?

YES! And, if consuming various forms of energy, the objective could be to reduce the addition of all energy costs.

There are two "focused" approaches ***Forced*** and ***Pareto***; and one ***Inclusive,*** taking the costs of energy consumption into account, or some other metric representing societal or political values. In addition, in some cases, are the advantages of Dynamic over Static optimization.

These approaches also apply to any other specific "interest" to be achieved by operations.

A. **FORCED: Add – or tighten – a constraint to energy consumption**. This method represents well a true limit on the availability of that energy resource, and could be used subjectively "to manage energy consumption in the right direction". The other performance metrics will achieve the consequent best possible balance. Note:

- Adding or tightening an active constrain will sacrifice other aspects of performance; thus while the focus will show improvements the overall (balanced) performance may or may not improve.
- If a constraint is tightened sufficiently, the process may become incapable of satisfying all constraints (minimum requirements) -- then constraints will need to be relaxed or the process itself will need to be improved, an engineering job.

B. **PARETO: Let the Performance Index be Energy Consumption to be minimized**, while applying realistic constraints to the other performance metrics. Thus, reducing energy consumption would take place subject to maintaining (or improving) the performance in the other metrics. This is Pareto Optimization.

In one such case (paper mill) the user saved 15.6% energy costs (electric plus steam). They got 7.1% savings just though better adjustments. Then, after Constraint Analysis they saved another 8.5% by enlarging a recycle air duct and fan, and the consequent optimal adjustments (see www.ultramax.com/Applications/Paper_Energy.pdf).

C. **INCLUSIVE: Add Energy Consumption as one of the metrics to be balanced in the Performance Index**, while keeping the traditional constraints on safety, capacity, and other minimum requirements.

This more comprehensive Performance Index is either the total economic impact on the P&L Statement -- or a fair surrogate with which you are more familiar. This approach in the long run may be more desirable for the firm -- but probably not as politically dramatic.

➢ **DYNAMIC OPTIMIZATION:** In addition to any of the three approaches described above, instead of a Static Optimization solution with constant process adjustments, consider **Dynamic Optimization**, compensating the adjustments for measured uncontrolled factors that affect operating performance.

Consider the simple case where an objective is to produce a product below a maximum level of moisture and there is no moisture feedback control mechanism in place. With Dynamic Optimization one can avoid the costs of over-drying by adjusting setpoints such as temperature, time and/or speed depending on the moisture content in the raw materials and/or the ambient humidity. Ultramax will learn automatically which inputs to re-adjust and by how much. The same mechanism will also protect against under-drying when the conditions are adverse, up to the capability of the process. And Ultramax can optimize performance even if there is already a moisture control logic – expected to be more rudimentary that the scope of what Ultramax solves.

3. In optimizing the performance of production / manufacturing operations, what does one do with the existing Process Control System?

As with the production equipment itself, the Process Control System (PCS) – hardware, the control scheme and sensors -- is usually used as is.

Managing or controlling process performance is done through plant personnel making **adjustments** to setpoints (and biases, parameters, etc.) that the PCS implements, including those with "Advanced Process Control" (APC) or manual physical adjustments. The main impact of Ultramax Supervisory

Control System is to provide the PCS with **adjustment values which optimize process performance**. Hence the motto "*Advanced Process Management*™".

A PCS is usually configured as a Distributed Control Systems (DCS) or Supervisory Control and Data Acquisition (SCADA) systems. Their control scheme usually includes:

- **Regulatory Control** (to keep controlled variables close to set-point adjustments).

  Normally the regulatory control scheme is used as is (if working properly).

  As a complement to direct regulatory control Ultramax can be used to effectively implement feed-forward balanced regulatory control of downstream variables beyond the reach of single loop or multi-variable control schemes -- see the CHEM example for *Viscosity* and *Solids* in the Blue Book.

- **Control Logic** (to determine setpoint values as a function of process conditions), sometimes.

  One needs to decide whether to *supplement* or *replace* any Control Logic with Ultramax, as they do similar jobs, except to Ultramax is usually more complete, encompassing more performance metrics. This decision has a large impact on the scope of optimization, including objectives and variables.

  If supplementing it – as done usually -- add a "bias" to each setpoint value determined by the Control Logic. For each, the PCS implements the addition of the value determined by the Control Logic plus the bias optimized by Ultramax (which also depends on conditions). If the control logic is optimal – which is seldom seen -- then the optimal bias will be near-zero for all conditions.

In addition, some users have reported success using Ultramax to optimize adjustable **parameters** (constants, factors, gains, limits, etc.) in the equations or algorithms of PID Process Control and/or Control Logic.

4. Does Ultramax perform "Process Control"?

These answers are dominated by the fact that Ultramax operates as "Macro Supervisory Control", where the "Run Time" with constant adjustments, or time between providing each adjustment modulation values, is usually between 15 min to a couple of hours, or a batch time.

Any 'Detection' or 'Process Control' function that requires faster response is not done by Ultramax; a separate procedure is needed, as there has not been demand for this function.

Ultramax does some kinds of "process control", depending on what is meant by it, as follows:

a. ***YES:*** **Statistical Process Control, Detection**, and more. Ultramax indicates for each new run data set entered, whether each variable's constraints (i.e., basic requirements) are satisfied, and separately it indicates whether output values are outside the expected (statistical control) range. In addition, both situations are reflected in the short Alert statements in the "Advice and Run Report". This happens as often as the 'run time'. Data plots show constraints (and thus any violations), and plots of data deviations from predicted values (as a function of the input values) show the control limits.

b. ***NO:*** **Feedback Regulatory Control.** Implemented through (feedback) manipulated variables to assure that the controlled variable remains close to target or setpoint. The feedback control logic does not know what created the perturbation, but corrects for it through known "gains" of the manipulated variable, up to PID loops, and in Advanced Process Control (APC) by applying multivariable Dynamic Matrix Control (DMC) and Model Predictive Control (MPC). Typical reaction time is in seconds or fractions. Ultramax does not perform this function; it counts of the existing Process Control System to do it.

c. ***NO:*** **Feedback Statistical Process Control (SPC), Corrective.** This is similar to Feedback Regulatory Control, but implemented through changes in adjustments of settings such as setpoints. The feedback control logic does not know what created the perturbation, but corrects for it through rules based on known "gains" of the adjusted inputs, typically each controlled variable analyzed separately (univariate). Typical reaction time is in minutes or longer. Ultramax does not perform this function; it counts of the existing SPC procedures to do it. Ultramax works better when the implementation is consistent, so as not to add another source of output variations.

d. ***YES:*** **Feed-forward Regulatory Control** or **Feed-forward Statistical Process Control, Corrective.** Both are the same thing, and executed through re-adjustments of settings. Ultramax will first assure that all constraints (basic requirements) are satisfied with reliability. Then, while maintaining that requirement, Ultramax will arrive at the most desirable balance among all output values, including those whose objectives are to be close to a target value. In doing so, it will also learn to compensate for **known** combinations of uncontrolled input values, such as raw material characteristics, and environmental conditions such as ambient temperature and moisture. The reaction time is the 'run time', but could be a few minutes when the analysis is triggered by a separate detection of important changes in conditions (uncontrolled inputs).

5. What is the relationship between Ultramax and Lean Manufacturing?

Lean Manufacturing, as a manifestation of avoiding waste (non-value-added) and not missing opportunities for improvements, has several aspects, such as:

- "Lean Design" (design of equipment and procedures, the most common emphasis today, a good complement to Six-Sigma)
- "Lean Scheduling"
- "Lean Safety"
- "Lean Scheduling"
- "Lean Operations" (implying routine running of the process, making any one product, with the current production assets)

Ultramax is a solution or tool-set to achieve the highest practical achievement of Lean Operations, namely, "**Optimal Operations**".

6. What is the relationship between Ultramax and Six-Sigma?

The relationship is large complementary, with the exception that Ultramax (UMAX™) is a great improvement on Design of Experiments for the objective of optimizing input values.

A. There is no Design of Experiments (DOE) software, for Six-Sigma or otherwise, which approaches what (UMAX) can accomplish when the objective is optimization and the data is obtained sequentially (such as when data is obtained one run at a time from a single piece of equipment):

> *UMAX optimizes without the disruptions and costs of experimental runs in production / manufacturing, or with fewer experiments when doing experimentation; and addresses multiple objectives automatically.*

This saves lots of money and aggravation in production, is simpler, and gets better results. In addition UMAX requires much less statistical expertise. (If you know of any equivalent software, please let us know at ultramax@ultramax.com.)

> Note, however, that when the objective is obtaining a deeper basic understanding of the workings of the process for a redesign project – a common task in 6-S -- the analysis from orthogonal DOE are superior to the analysis from UMAX. On the other hand, knowing the location of the optimum is a great contribution to understanding the basics.

B. There is commonality between 6-S (Quality Control) and UMAX:

- Both rely on team work. Both are more than just instruments, they are a method and approach to have a more effective mind-set on how to run production.
- There is commonality when 6-S calls for doing on-line Statistical Process Control (SPC) during production operations to detect (abnormal) process upsets. UMAX is more refined because it discounts the effects of known uncontrolled inputs.

C. Mostly, there is synergism between Six-Sigma (6-S) and UMAX.

- An ideal scope of 6-S could be significantly expanded with sufficient awareness of the power of Sequential Empirical Optimization. Then UMAX would be a magnificent contributor.
- UMAX helps identify barriers to further performance improvements which lead to focused 6-S and re-engineering projects.

Also,

- The increase in consistency obtained by 6-S process improvements is desirable for UMAX, because UMAX gets as close to the optimum as about one sigma of the noise (the unexplained output variability, after discounting for known uncontrolled inputs).
- In turn, reducing variability is often part of the objectives selected by the customers in using UMAX for managing discrete production / manufacturing operations (whether applied on-line or used for studies), which coincides with a main objective within 6-S.

7. It is possible to use historical operating data to check out the quality of the models?

Yes, it is readily possible to import valid historical data into Ultramax®, plot the data, create useful "preliminary" models, detect outliers, check constraint satisfaction, etc.

However, historical data is not adequate for model creation quite frequently. There are two issues to watch for:

A. For the models to be relevant for optimization they need to be cause-and-effect – not just correlation models as can be created with any data. To create empirical cause-and-effect models the adjusted inputs need to be independent of each other; that is, in adjusting any input there is not a mechanism that automatically changes another input (if there were any, then the one affected is an output, a consequence). Correlation models are useful to predict values as long as one is only an observer, that is, <u>one do not intervene on how the system operates</u>... and optimization is to intervene by making better adjustments.

B. As it is well understood, for the models to make sense, the outputs need to be a consequence of the input values. Thus, in continuous processes it is important to make sure that output values not be affected by previous inputs values; that is, to avoid including transient data created by re-adjustments (unless one is using the "Transient" version of Ultramax).

8. Statistical Training required

It is known that to interpret efficiently the data provided by Ultramax's report, the user needs to understand some basic statistical concepts. Anyone trained in introductory statistics and/or quality control, or anyone trained with the statistical or quality control requirements expected from a modern production facility, has sufficient background.

To summarize, the basic concepts to understand at the "gut" level are: **mean, standard deviation, and the** significance **of 3*sigma in decision making.**

Failing the above exposure, in order to learn these concepts, take any introductory text in statistics and quality control, and study:

a. population, histogram, distribution of continuous random variables

b. mean (average), mode, median

c. measures of dispersion (variance, standard deviation, sigma)

d. probability table of a "normal" distribution

e. sampling, estimation, confidence range of mean estimate

f. the standard deviation (or sigma) of the algebraic addition of various independent random numbers: the variance of the sum/subtraction is the sum of the variances

g. the first couple examples of "test of hypothesis" to get the basic idea. If the book includes it, also study "comparing two averages"

h. basics of control charts for (continuous) variables

A book may take a few hundred pages to cover all the above concepts; so, you may prefer to avoid unnecessary topics. For instance cover only the statistics of continuous variables; do not bother with discrete concepts such as number of “defectives” or number of “failures” such as in the binomial or Poisson distributions. Do not bother with refinements such as chi-square, student-t distributions, or get too heavily into probabilities and risk analysis.

9. Is Ultramax designed for operators or for engineers?

Setup (especially formulating the Optimization Plan) is designed for managers/engineers, with participation of operators to be aware of some details and for them to participate in the “big picture”.

Running the process with Ultramax is designed primarily for operators, with support by engineers/managers when problems appear. In one case an operator totally new to Ultramax become practically self-sufficient and eager to continue on his own in less than two hours participation in Sequential Optimization, except for the proper reaction to the Alerts.

Preliminary routine **evaluation** is designed for operators. **Analysis** of potential problems and of overall performance and gains is designed for engineers/managers.

10. What do we do after we converge to optimal operating conditions?

The issues in maintaining the optimum are:

A. That the process be kept in control (maintain consistency; data be valid – equivalent to run-by-run statistical process control); and to continue getting the Alerts and Status descriptions offered by Ultramax.

B. Compensating for known changes in uncontrolled inputs

C. Adapting to slow changes in unknown uncontrolled inputs

D. Whether noise is already a fraction of the MID (i.e., whether you are at the Relative Optimum or the Practical Optimum?)

These issues are explained in the Blue Book in Part 2: Operating Procedures > Maintenance, Discovery and Improvements > Maintenance and in > Appraisals

11. How often should we run optimization cycles after getting to an optimum?

Without a correction from the above analyses, e.g., for a boiler:

- If ***Stand-alone***, run a cycle once every two-four hours. However, some customers have created a system where only an Advice is obtained in the cycle, and data is collected separately and entered once a week by clerical personnel. There are a few methods to do this.
- If the integration mode is ***Advisory***, every two hours.
- If the integration mode is ***Closed-Loop***, let it run, it is the best of all possible solutions.

12. Does Ultramax converge to the global optimum?

Often yes, regardless of where it is as compared to prior knowledge. However there are exceptions, as follows:

The Sequential Empirical Optimization (SEO) in Ultramax attempts to increase production performance as much as possible as soon as possible. If this technology is applied automatically, without end-user direction, SEO is limited to converging to some local optimum. This local optimum may be the global optimum; and will be the global optimum if there is only one "local" optimum. Ultramax will converge to the optimum with fewer runs than any other empirical technology today. Note: the concept of "optimum" includes satisfying constraints.

Put in other words, after converging to an optimum, the SEO algorithms do not include any logic to go down towards lower performance to explore whether a "bigger mountain" exists on the other side of the valley.

The way by which this SEO would go to the bigger mountain is for an engineer to make a few runs at the bigger mountain, and entering that run data into Ultramax so that it can become aware of the potential greater performance in that region. Making these exploratory runs is considered doing experiments in a R&D project, not part of the ongoing operations.

13. Why the Dynamic aspects of Ultramax are emphasized so much?

Ultramax, like Neural Network solutions to adjust a production process, is an example of a "decision support systems" (DSS, as it is known to Industrial Engineers, Operations Research and Management Science professionals.)

An important characteristic for long-term profitable impact of a DSS is that it needs to represent and keep up with reality as it changes. Virtually nothing remains constant or static. Some relevant aspects of reality are the 'elements' of importance, the' behavior or interaction between the elements', and the 'objectives' of management. An effective DSS must have reasonably easy ways to keep up with the changing reality; else its profitable life is limited.

This adaptability exerts a price: the DSS needs to be managed and maintained. No DSS (known to me) that can be implemented and virtually forgotten because it maintains itself.

As compared to any solution that is based on creating mathematical models up front (such as DOE, NN or First Principles), Ultramax excels in terms of dynamic representation of reality, and thus in providing longer-term satisfaction of the customer and the parties the customer needs to satisfy. It also does this at a relatively low cost.

With Ultramax the prediction models relating inputs to outputs – the behavior of the process -- maintain themselves automatically; as long as the user determined that the system is Dynamic, and keeps on supplying good quality data. In addition, changes in elements and in objectives are very simple to implement. The ability to do this is largely based on the underlying technology of Sequential Empirical Optimization, where there is a renewal with each new process run data.

In addition, the "Discovery" aspect of Ultramax enhances the ability to reformulate the best scope and criterion for optimization (the Optimization Plan) since it is so easy to do. See the Blue Book > The Macro Cycle of Improvements ~page 73.

14. Why are probabilities – such as probability of violating a quality limit – NOT mentioned almost at all?

As a side issue, recall that in order to better satisfy your customer, advanced quality considerations call for quality characteristics to be either close to targets, as high as possible or as low as possible. This was proposed and practiced by Ultramax Corporation since 1983 and by Dr. Taguchi in the USA later that decade. Focusing on the probability of conforming to quality limits (being within specs) is a secondary consideration, which is mostly legalistic and a legacy from traditional over-20-year old practices – still present in some places, unfortunately.

Now to the main question: Probabilities depend on the distribution of the data, a distribution which is known only as far as the mean and standard deviation, no more.

We might be tempted to assume that that distribution is "Normal", but (contrary to what many elementary statistical approaches say or imply) individual data is seldom near-normally distributed, especially at the extreme values. This also applies to the distribution of averages of data within short periods of time, when it is subjected to longer term disturbances creating the overall distribution.

Of course, due to the Central Limit Theorem averages of over 5-10 numbers (randomly drawn from the entire population of interest) approach a Normal distribution. This condition applies very seldom in SEO. It does apply, through, in performance comparisons to evaluate gains.

Thus, in Ultramax we extremely seldom mention risks and probabilities associated with single data, and thus we only go as far as referring to protection and risk by the "number of standard deviations". As Dr. Shewhart already understood, the famous 3-sigma – applied in Ultramax for true constraints -- is practical and relevant regardless of the distribution.

15. What is Ultramax not?

The Sequential Empirical Optimization (SEO) technology in Ultramax is not:

A. *Design of Experiments (DOE) and Response Surface Analysis*: SEO solves similar problems; however, DOE is suitable mostly when the system is dedicated to obtaining data for *experiments*, seldom while *engaged in actual real-time operations*. Further, DOE results are not easily adapted to changing conditions or requirements, as is managed so well with SEO.

B. *EVOP and SIMPLEX*: SEO is a third-generation descendent of these 60's technologies, but one exploiting modern computational power and advanced technology to be strikingly more thorough and effective. It is vastly superior and more flexible since it is less sensitive to noise, provides significantly higher cumulative performance, and can compensate for uncontrolled inputs.

C. *Neural Networks*: These require an immense amount of operating, experimental data before producing useful models. Consequently it takes a long time to identify the optimum, and that only to the optimum is the region covered by the existing data. SEO, by contrast, extrapolates quickly into promising but previously unexplored regions. The creation of Neural Network models also requires substantial investment from human experts, today it cannot be done "live" reliably. An advantage of NN is the ability to identify multiple local optima (in the region of collected data).

D. Regulatory Control (PID or multivariable) logic, which aims at maintaining controlled variables close to predefined targets (setpoints). The aim of SEO is optimizing performance through defining better targets (and other decision variables). SEO depends on the effectiveness of existing regulatory control. Relative to this it is second-level or optimizing control, which includes maintaining output values beyond the reach of existing regulatory control close to targets.

E. *What-If decision table.* A what-if table – popular in some areas of Artificial Intelligence – determines a recommended decision given the values of several known conditions. This relationship must be configured up front, based on personal experience or more advanced mechanistic studies. By comparison, SEO **finds** the near-optimal decision and does not require anyone to have a pre-conceived or pre-experienced answer to start with. Further, when SEO is on-line and constantly updated with new operating data, it maintains its awareness of the optimum even as unknown process or conditions change (unknown changes only when they change slowly).

F. *Optimization with First-principles models.* That is, optimizing a model of the system where the cause-and-effect relationships between variables are known with sufficient accuracy and completeness (such as we learn in engineering school) and coded within software tools. On the other hand, Ultramax can accept full or approximate process models as a starting point.

16. What is the role of (standard) Acceptance Tests for the Ultramax installation?

Sometimes customers request an Acceptance Test, as it is normal with the implementation of any new technology. Ultramax also offers a surprising superior alternative for the consideration of the customers – what might be called "continual performance evaluation and acceptance test".

One of the interesting intrinsic characteristics of Sequential Optimization is that the technology itself needs to evaluate performance on a continual basis in order to learn how to do better. Since the evaluation is done with the metrics and criteria defined by the customer (*never* by a service agent), the customer also gets continual evaluation of production operations performance in their own terms.

This evaluation with ALL the runs is much more thorough than an Acceptance Test of short duration, except to the extent that during normal operations there were disturbances that one might wish to ignore.

In addition, the performance analysis procedures call for periodic Baseline runs (at the baseline adjustments, also defined by the customer) as part of Triads. This evaluation is considerable more thorough than an Acceptance Test of short duration. One of the reasons is that regular Acceptance Tests would provide information only for the very limited experience of uncontrolled inputs experienced during the test. Another reason is that for a test to be a proper reflection of Ultramax performance, the combination of uncontrolled inputs during the test need to have had sufficient history (else, Ultramax is still in the dynamic stage of learning how to optimize for that set of conditions).

In conclusion, analysis from the observed results from actually running Ultramax is significantly more informative than any acceptance tests of short duration, except for possible disturbances that one might wish to ignore.

Normally, Ultramax proposals presume that guarantees of performance are checked with all the run data and no costs are allocated for a separate Acceptance Test. Note that if the guarantee needs to be based on an Acceptance Test, then the test needs to sufficiently long to avoid the limitations mentioned above.

Even if the customer wishes to perform an Acceptance Test for traditional reasons, the customer should also want to have the analysis based on all the runs made with Ultramax, what we call the "Progress Report".

17. What if the advice provided by UMAX results in bad consequences that the user does not know about?

One solution to this is to provide input constraints so that optimization takes place in the region of adjustments where there is confidence that bad consequences do not take place. This provides the security and peace-of-mind required, but may hinder progress.

Then, proceed with sequential optimization until the relative optimum is reached within these limits. Then, analyze the active input constraints with experts to see how much further the constraints can be moved out before creating undesirable consequences, perhaps adding new sensors to measure the aspects of risk (such as a temperature). Repeat the procedure above until the constraints cannot be moved any more (this is part of what is called "sensitivity" analysis in the Blue Book).

If in spite of the advice of the experts bad consequences happen, then count this as the cost of learning and progress.

18. What if after changing an adjustment something goes wrong before UMAX can react to it?

The solution to this is the same as if the operator had made an adjustment by hand – if bad results are obtained then it would back away and learn from it. This would happen, for instance, when going over a ridge and hitting the down slope beyond.

UMAX is not a control device; it is automated (and optimizing) supervisory control. In the case of closed-loop UMAX sequential optimization, it is the responsibility of the user to determine that the implementation is reliable.

Recall than UMAX has Alerts to indicate when the adjustments are moving into new territory, and that the user can tune the alerts as to when to shift closed-loop optimization to advisory optimization.

19. What is the effect of the value of MID on the speed of optimization?

As a matter of principle, it is good that numbers be close to what they were meant to be. The MID for each output means that this is the difference in performance that management would really notice (e.g., the changes in value of the Performance Index, or a minor violation of constraints). Noise much larger that the MID indicates (à la Deming) that management is constantly upset because unexplainable and unpredictable values happen. This psychological upset cannot last very long, and if the problem is not fixed, true MIDs will start increasing.

Now, as far as the mechanics of optimization, having a constrained output MID smaller-than-real affects optimization in that the Effective Operating Area is reduced. However the speed of getting there will not be affected much as Ultramax knows the noise level, as it is guided by that, not the MID. On the other hand, having an MID much larger-than-real -- and much larger than the noise -- will affect the ability to optimize, as Ultramax maintains output spreads larger than MID.

The benefit of the extra spread is to have more robust models, with differences in performance which are not important to management. In particular, the models do not get hung up with small unimportant details of the response surface behavior, and have a better chance to detect changes due to unknown uncontrolled inputs.

20. What can we do to speed up SEO, to make it more aggressive?

Taking bigger steps in SEO has the potential advantage of converging to the optimum faster. Also, it has these potential negative effects:

a. increasing the risks in making runs with undesirable performance (such as violating a constraint or running into a valley). This may sacrifice cumulative performance, the main performance characteristic for production management (but not for making experiments and tests).

b. missing finer details in the response surfaces

c. decreasing the range of safety when and if, due to random effects, Ultramax looses sufficient consciousness about process behavior

Steps to increase the aggressiveness of SEO (many explained in the Blue Book > *Appendix* > *Ultramax Parameters*:

i Increase PAR(10), Aggressiveness, the size of the Area of Confidence

ii Increase PAR(59), the maximum adjustment change, in units of MID for all adjusted inputs. To avoid the limit on maximum change in the adjustments, set PAR(59)=0

iii Increase the size of MID for individual adjusted inputs [if PAR(59)>0]

iv Increase MID for outputs, to extend the Effective Operating Area when it is reduced by relatively high noise

v Reduce PAR(30), the safety required (in number of sigmas) not to violate output constraints by more than MID.

21. What is the basic relationship between Noise, Signal and MID?

An empirical solution is based on data from the process.

Noise is the enemy of modeling and optimization for any empirical solution.

Noise is the variation in outputs that are not explained by the known values of the (control and uncontrolled) inputs. Noise can be reduced by: taking better measurements; including the inputs that causes or is related to the variations; reducing the variations generated by the process itself (including procedures followed by the operators and control logic).

The “filtering” of noise is performed by regression analysis. Often the models are more accurate than the data. The variation in outputs explained by the variation in the inputs is the R-square. The equation of the R-square is obtained from any statistical textbook and from the internet. We use the R-square corrected by the degrees of freedom – that only advanced books explain -- and call it the Signal. Following is the equation for R-square, however, having the equation is not quite sufficient to understand its meaning – you need to have some experience with it.

If **e** is the vector or residuals, and **y** is the vector of deviations of outputs from their average, then

$$R^2 = 1 - \frac{e \bullet e}{y \bullet y} \quad \text{that is,} \quad R^2 = 1 - \frac{variance\_of\_residuals}{variance\_of\_outputs}$$

$$\text{Estimated Noise} = \sqrt{\frac{e \bullet e}{K - P}}$$

where K is the number of data points and P is the number of model coefficients.

The Critical Signal is the minimum signal of all the outputs that need to be predicted well for optimization, namely the objective function and the active constraints.

When the critical signal is larger than 65% then almost without failure we achieve quick improvements, but we have achieved improvements with lower signals. Signals are not accurately defined until there is sufficient data for full models, namely after having these many data points (with different inputs): (N+1)*(N+2)/2+2N where N is the number of inputs.

Further, to fully satisfy management needs, it is desirable is that the noise be less than the MID. The MID represent management/business needs, thus, they cannot be “adjusted” to be more successful.

An important way in which noise prevents approaching the optimum better is to prevent to get too close to the constraints in order to avoid violating them.

Most often Ultramax gets quickly as close to the Safe Optimum as 1 to 3 sigmas of the noise of the Performance Index and constraints. For this reason alone we can get better results by lowering the noise. Reducing noise may improve the Safe Optimum (that satisfies constraints reliably).

22. Is it better to enter calculations into Ultramax, or to make the calculations before providing the data to Ultramax?

It is much better to include the calculations in the Optimization Plan.

The benefits of entering calculations in the Optimization Plan (through GUI calculations or through a .DLL calculation file) as compared to using the calculations externally to provide data to UMAX® (rather than keeping them outside, such as in the DCS or historian) are:

1. Converge faster and closer to the optimum, as illustrated in the examples below. The faster convergence is because of using true models rather than the approximate models fitted to noisy data; i.e., not having to “learn” the characteristics of the calculations.
2. Automatically update historical calculated values after entering new data to substitute earlier poorer estimates or missing data -- rather than having to recalculate the values off-line and enter them by hand

3. Maintain process optimization responsive to changing business conditions. The only thing that is necessary is for higher management to change the Global Factor values used in the calculations, and the rest happens automatically. Global Factors are used to calculate the economic or quasi-economic Performance Index to represent business priorities and economic conditions.

4. Refine process optimization as technical calculations are improved.

Note that #2, #3 and #4 include that all historical calculated variables are recalculated automatically with the new corrected data, global factors and/or calculations.

Further perspectives:

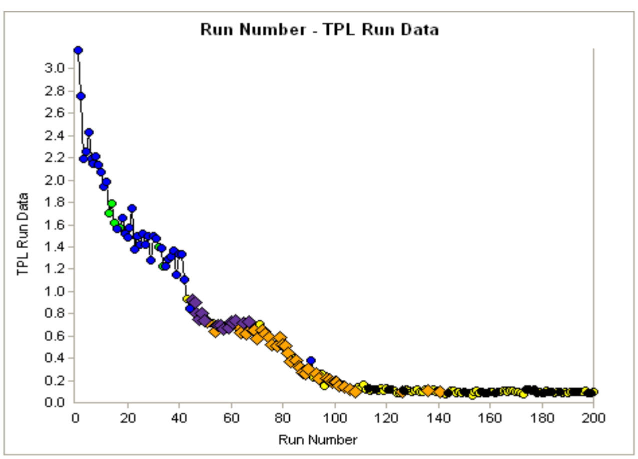
In the extreme, if all outputs were calculated, then one would not need any physical data to optimize (i.e., to create fitted models). Then optimization is no longer Sequential Empirical Optimization (SEO), but fixed-model based. The fixed models could be either First Principle or Empirical (such as Neural Networks or RSM from Design of Experiments).

Recall also the Prior Model feature in UMAX. Here the user provides to the Optimization Plan "prior models" for some or all the outputs. Then:

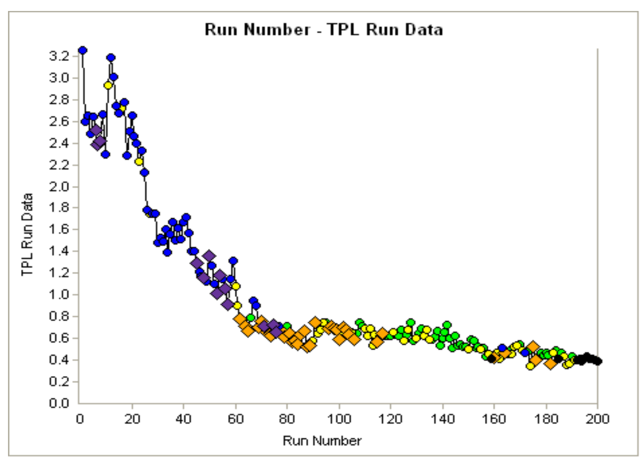
- UMAX creates a correction model to be added to the Prior Models, thus correcting for imprecise original (prior) models.
- If all outputs have Prior Models, then an advice without data is the optimum as defined by the Prior Models.

Below are some results obtained with simulated processes (similar to the CHEM example in the Blue Book)?

- ➢ 20 inputs, 50 physically measured outputs, and four calculated outputs, especially, the Performance Index (Objective Function)



Outputs calculated inside Ultramax



Outputs calculated outside Ultramax

23. If I change the equation of a calculated variable, will this calculation be applied to past data? What about changing constraints and the objective function?

Yes, it happens automatically. All past data is always evaluated according to the current Optimization Plan.

24. Should actual data for inputs be the desired values (the adjustment, the decision, the target, the demand) or should it be the actual (controlled) process input values generated by the first-level regulatory control system?

If the first-level controller works well all the time then there is very little difference between which one is used. The question remains for when the first level controller is not working that consistently. Then:

If we use the adjusted value (the desired or target value) for the inputs, then we generate models that relate decisions to the outputs. These models are ideal to find out the better decisions. However, they include the noise generated by the imprecise first-level controller (including hysteresis effects).

If we use the physical (controlled) value for the inputs, then we generate models that relate the actual, physical values with the outputs, without the controller noise. Unfortunately, especially so when there are problems with the controllers, it could be that the various inputs are not independent of each other, which is a necessary condition for good empirical modeling for decision making and intervention in process operations (It is not a requirement for uninvolved predicting). This approach gives a better engineering insight about the cause-and-effect mechanism within the process, but <u>it does not readily resolve the problem of knowing which adjustments to make in order for the actual to be the desired value and to get the consequent predicted results</u> (to do so we will have to use cascading control as described in the Blue Book "Intermediate Variables as Inputs". There is one case where this model would be better, when controller problems are about to be resolved.

In conclusion, it is better to use the adjusted value as the input, not the actual.

If one wanted to test whether the adjusting mechanism is working well, we could have both the adjusted and the actual controlled value as variables. The actual is a consequence of the input(s), and for the Ultramax Optimization Plan it is an output or consequent variable. Then we could calculate the difference between the actual and the adjusted. This will give two kinds of information: (1) if the difference is regularly too large, then the engineer would know where there is a problem; and (2) when a new actual difference exceeds historical values this would be detected by the standard errors and informed to the operator to check what is going on.

25. How do we proceed when uncontrolled input values will not be known for a few optimization cycles (e.g. data from a lab test)?

Note: There cannot be unknown adjusted input values (decisions made); and unknown outputs values are simply entered as "--" (undefined or unknown) until the value is known and entered (editing data base). When getting advice, the forecast for the values of the uncontrolled inputs in the future cycles is likely to be the latest value know.

There are two alternatives to enter actual data:

a. Enter as uncontrolled input data the latest known values. Then, when the actual values become known, enter them into the data base instead of the old estimates.

   This is a good approximation when the values do not change much from run to run.

   Disadvantage: advice will be based on prediction models created with somewhat erroneous data.

b. Enter “--”. Then, when the actual values become known, enter them into the data base. One must get at least as many advices as will be necessary until the actual data becomes available.

   Disadvantage: since the Area of Confidence is created only with the complete data, the advices will not advance as fast. Thus the advices will be more reliable but most likely converge slower to the optimum.

The fastest the uncontrolled inputs change from run to run, and the closer to the optimum the runs are (SDF<<1), the more desirable alternative b is.

26. Do you expect to see more performance improvements with DCS integration than with Stand-Alone installation?

If you *get exactly the same data* from the process, there is no difference between a Stand-Alone and Integrated installation.

However, more realistically, the answer is YES. Some of the advantages of integration are:

Takes less work on the part of the operators, and thus the life of the application will be longer, yielding more value to the customer. In particular the easiest solution, Close-loop optimization, is not possible.

Integration facilitates making all crews work the same way, thus increasing consistency – good for business and to reduce this source of noise.

Integration prevents certain human errors (a source of noise) in the data, such as errors in setting advices, reading data, calculating averages (for actual data and for predicting uncontrolled inputs), and typographical errors entering the data by hand.

Some advanced solutions, such as Transient Optimization, can be done practically only with closed-loop integration.

27. How does Ultramax do "Constraint Management"?

At an operational level, Ultramax takes constraints as limits imposed by the end-user (and it can calculate variable constraints). Ultramax’s SEO:

Maintains the adjustments within their constraints.

Tries to maintain output means within the constraints over 50% of the time, and within MID beyond the constraint most of the time. The Alerts and the data in the Advice report tell you whether it seems impossible for the process to satisfy these requirements. The Consistency Test also indicates whether these satisfy the requirements.

The USER does Constraint Management in the Blue Book > Maintenance, Discovery and Improvements > Appraisals by seeing which inputs and outputs are active, and moving or removing the constraints in order to increase the Objective Function. As an off-line Engineering Analysis task with the software, the user can change the values of chosen constraints (by hand), re-optimize, and see the effect on the Objective Function in the consequent Optimum Estimate.

28. How does Ultramax do "Data Validation"?

Data Validation is to check whether the data is valid, that is, nothing seems to be incorrect. Sources of deviations can be sensor malfunction and upsets with the process, including control logic and procedures. This is Data Validation at the supervisory control level (second level control).

Data validation for, e.g., a nonfunctioning or malfunctioning sensor, is done at the process control level (first level control, including APC) within the DCS. If the DCS misses something, then Ultramax's data validation might catch it.

The main Validation test made is to measure, separately for each variable, how close new data is the distribution of past values. The measure is in "number of Sigmas", and it appears is a dedicate column in the Advise Report, and when exceeding certain thresholds, in Alerts statements.

Ultramax also does output data validation through the mechanism of the "standard errors", whose values appear in the Advice Report for each output; and in the Overall Standard Error, a multivariate measure. Outliers at different levels are also shown IN Alert statements.

Note that extrapolating into new regions of performance is likely to trigger detecting large deviations. Small drifts in sensors will not be picked up by this logic.

29. Can we include any data collection before starting optimization cycles in the regular UMAX application file?

Yes is we designate where the first optimization run at Baseline adjustments is, in PAR(3). The reason other data with constant inputs is not included in the analysis that they have too little information and this would mislead the algorithms in Ultramax.

30. Do the periodic, Baseline runs made during SEO slow down its progress?

Yes. If we make a Baseline run every ten runs or son, then, if instead we follow the Advice, then we would have made progress about 10% faster. This is a "price" of having to:

- satisfy customer desires to <u>prove</u> improvements
- to see clearly the effects of changes in uncontrolled inputs as a function of time, or even failures, by having a series of runs with the same adjustments.

Periodic Baseline runs will be stopped when management declares trust in Ultramax. Then, a loss in consistency will be detected through the Standard Errors and the Capability and Consistency Analysis.

31. What is the Historical Achievement Analysis?

The Historical Achievement Analysis finds how close the SEO runs are to the optimum (the latent gains, extra potential gains, or unrealized gains) for the same values of the uncontrolled inputs. In general, there should be a trend to lowering the latent gains. However, even in a good round of SEO optimization the latent gains do not have to get consistently smaller when there are important uncontrolled inputs. The latent gains can increase (apparently undesirable) because: (a) every time a new combination of uncontrolled inputs appears the latent gains are large until Ultramax learns to optimize; (b) the optimal (minimum) latent gains are different for different values of the uncontrolled inputs.

32. What is Bayesian statistics?

Bayesian statistics is based on a different structure than Classical or Fisherian Statistics. Some of its characteristics are:

- Knowledge is represented by statistical distributions. “Prior knowledge” is modified by new data to become the more refined “posterior knowledge”.
- Data is considered something fixed, while distributions are random and unknown; the opposite than Classical Statistics.
- It is very suitable to business decision processes with imperfect knowledge; Classical statistics is more suitable for scientific true-false statements.

Within Ultramax’s sequential optimization (learning after each new process run, the main great advantage of our approach) this approach pays off mostly when there is little data, where classical statistical methods cannot even suggest an answer.

For instance, imagine:

- A process with two adjustments and one result to be maximized
- The two adjustments are represented by two sides of a room, and the results by height
- Two process runs (with different adjustments and different results), which correspond to two points in space in the room (while explaining this, hold the point at the tips of the thumb and index finger of each hand).

Now, we ask the question: in which direction should we change the adjustments next with the highest likelihood of improving results?

The simplest prediction model structure that would recognize the effects of the adjustment inputs is a linear model with three parameters (a constant and a coefficient for each input).

Classical statistics cannot create a prediction model with the above data (there are two data points to estimate three parameters).

Bayesian statistics can create such a model; and the result matches what our intuition indicates: move adjustments from the lower height run towards the higher height run, going beyond the higher run adjustments[1].

The above holds true for any number of inputs! Thus, if we have 20 adjustments, Ultramax's sequential Bayesian models will likely be obtaining performance improvements starting from the third run, while classical statistics cannot even venture a guess until the 22nd run. Neural Networks, having many more coefficients, is much worse in this respect.

In estimating with a lot of data both statistics give similar results, and when the difference is not important for the decision or assessment problem, one may as well use Classical Statistics, which is computationally much simpler.

33. What is Weighted Regression?

Weighted regression analysis is a standard solution in regression books, where each data has different weights or scores associated with it.

What is new is the interpretation of data weights to represent "desirability to include" to estimate in an area of interest with more accuracy – and avoid the distortion of fitting data away from the area. This results in "focused" regression, creating models more accurate but in a local area of interest; as compared to less accurate but with more widespread coverage with descriptive regression (when all data is used equally). The area of interest for Ultramax is the area of best running conditions.

Weighted regression in Ultramax is done only after there is sufficient data to be able to calculate all model coefficients plus sufficient data to calculate the noise.

34. How come that when there is known bad data, sometimes the Signal (for outputs) and/or the Detected Effects (for inputs) appear large, making the variable apparently more relevant?

Clearly, common sense would indicate that bad input data should render that input as inconsequential (little detected effects).

It is known from development experiences that including bad output data can increase the apparent relative importance of an input without effects.

The signal is the dimensionless number:

$$\text{Signal} = 1 - \frac{\text{output noise variance}}{\text{output variance}}$$

namely, one minus the relative output variability not explained.

Thus, high signal is necessary but not sufficient.

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[1] The MID indicates how much further we can go.

Bad output data: It is conceivable that bad output data may increase the output variability more than the noise, and this will increase the signal. This may happen when the error coincides with some changes in inputs, even some without true effects. Then those inputs will appear with large detected effects.

Bad input data: Similarly, an input can product a faulty increase in the detected effect of that input.

The detected effect of an input on an output is, in principle, the dimensionless number

$$detected\,effect = slope \bullet \frac{input\,variability}{output\,variability} \bullet output\,signal$$

(There is an extension of this to the second-order effects also.)

If the slope were calculated properly, then the slope of an input without effects is (ideally) zero. However, due to confounding of inputs and to noise it is never zero. Then, an error in inputs that increases the input variability more than decreasing the calculation of slope will increase the apparent detected effect of the input. All these problems are aggravated with little data, such as when we are just climbing the mountain of performance.

In conclusion, the Signal and the Detected Effects are indicators only, not definite measures. Perhaps it may be true that if they are small then they are correct, but if they are large, which gives us comfort, they may be false (false positive results).

Further, note that we never talk about calculating the "importance" of an input, rather, of "detected effects". This is because an input can be very important, but if it is not changed sufficiently (small input variability), then its effect cannot be detected.

We may have to consider ourselves fortunate that in spite of this lack of quantitative clarity Ultramax has a track record of obtaining improvements, especially when we can assure that the data is of good quality.

Another note: the sequential optimization algorithms do not use the concepts of Signal and Detected Effects, they are calculated only for reports for the user.

35. How come sometimes a Prediction Model plot shows an opposite slope than the Actual Data plot?

This refers to the plot of one output vs. an input.

The syndrome may happen because the output actual data is a function of the actual values of all other inputs as well, while the prediction model plot is for all the other inputs remaining constant.

In geometric terms the data is a “projection” of all dimensions, which reflects BOTH input data distribution and the effects of the process response surface. In comparison, the prediction model plot is a “cross section” of the predicted response surface, independent of the input data distribution (except in its calculation).

Further, when there are interactions between the inputs (as it happens virtually all the time) the prediction slope depends on the values of the other inputs (the Reference). Proper selection of the Reference may show slopes of different sign.

36. How come Ultramax does not emphasize identifying the vital few most important inputs to control?

Actually, the Ultramax Method does, but only to the extent that it calls for all the inputs to have a significant effect on at least one active output "as perceived by people with process experience". The Method also recommends including inputs that "might" have a significant impact <u>after</u> optimizing with the more positively known inputs.

The main consideration in this approach is to get improvements faster, for the satisfaction of the end-user, even though it may be sub-optimization. For all practical purposes we always engage in sub-optimization, especially when we include the possibility of discovering new solutions to optimizing a process (e.g., constraint management).

The implications of the question is correct in that Ultramax does not consider the "cost" associated with managing and re-adjusting an input, the basic reason why it is desirable to have fewer of them. Note in particular that once the DCS control logic is installed, the act of re-adjusting inputs incur no extra cost.

Now, including inputs that do not affect results in the Optimization Plan incurs the cost of delaying converging to the optimum. However, running experiments (such as screening experiments) to find out which are the important inputs also delays converging to the optimum. That data may as well be used to do optimization; thus we do not recommend doing experiments to identify the few most important inputs. Eventually Ultramax understands which inputs have high detected effects.

37. How do we handle a case of many sets of adjustments (decisions) producing similar operating performance; i.e., there is some redundancy?

Let us imagine a case of a total air flow controlled by a fan and the flow being distributed among three ducts each with a baffle opened a certain % amount. We see in this situation that there is a certain level of redundancy in the control decisions, which may lead to alternate control strategies by different operating personnel.

Let us consider two cases:

There are adjusted inputs (i.e., decisions) for: the setting of total flow F that is controlled by a fan speed by feedback; and for the position of each of the baffles A, B and C.

A characteristic of this situation is that what determines process operations is mostly the <u>relative</u> amount open for the baffles rather than the actual amount. Thus, one could say that if they are open A=30%, B=40% and C=50% operations would be (largely) the same as A=33%, B=44% and C=55%.

In this case UMAX will see a "top" of the Performance Index mountain as a ridge with similar heights for various sets of {A,B,C}. UMAX will converge to the top of that ridge and will understand that in the direction of the ridge there is no much change in the Performance Index. However, UMAX understands only <u>one</u> optimum estimate at any one time. Thus:

The position of the optimum estimate along the ridge will be highly affected by past noise, and thus frequently changing – but outcomes being about the same.

The SDF of the Optimum Estimate will change a lot, thus not registering that the optimum has bee achieved (as would happen if there is one input that has no effect on the active outputs).

When SEO keeps changing the adjustments of the adjusted inputs in order to maintain the robustness of the prediction models it will tend to "travel" mostly along the ridge.

So, UMAX does not understand that there are different sets {A,B,C} which get the same (similar) results.

In this case there is a problem as {A,B,C} approaches "all 0%", in which case we may go beyond the fan capacity to maintain the F flow given the constrictions. Approaching 0% will be reflected by poorer process operations and by worse Performance Index. Thus, UMAX will not approach close to 0% open. To help avoid closing any dampers, we might wish to place a lower constraint on them, such as 5% rather than 0%.

A secondary consideration is that smaller sets of near-optimum {A,B,C} will make the fan consume more power, that is, larger operating costs. There are three solutions to consider this effect:

Keep one of the baffles "fixed" at a reasonable value. This reduces the number of adjusted inputs, and thus makes SEO converge a little faster. At any time this variable could be changed from "unused" to "control".

Include power consumption as a factor in the definition of the Performance Index.

Add a set of logic to have conceptual {A,B,C} adjusted inputs or decisions, and actual {A,B,C} settings (ruled inputs) such that always at least one of them is as far open as possible. To my recollection this has not been done by past users. In principle this can be done through entering into the Optimization Plan the required logic to calculate the actual settings.

There are adjusted inputs (i.e., decisions) for: the fan speed S; and for the position of each of the baffles A, B and C.

The situation is similar, except that now we would have sets {S,A,B,C} with similar operations (with larger S and smaller A,B,C being producing similar results). The same principles and solutions apply.

38. Is it possible to do integration communications with protocols other than OPC?

Yes, there are alternatives, as described below; but this is only a technical answer, not a proposed alternative. Note that if the DCS (or equivalent module such as a historian) already has an OPC server all other solutions are more expensive and less reliable.

It is possible to convert data in many media to OPC through some kind of Converter Server. Thus, we may conceive of a customer maintaining data in an ASCII file, an Excel file or in PI ProcessBook, and convert it to OPC for the UMAX Client OPC to get it.

39. Sometimes my operating objectives are to maximize yield, and at other times to maximize throughput; how do I maintain optimization in this case?

The most direct solution is simply to have both “Yield” and “Throughput” as outputs, and redefine which one is the Performance Index as appropriate.

There is a more comprehensive solution: When the shift of priorities is due to changing business conditions (e.g., unit prices, unit revenues) and is guided by trying to maximize profit generation, then:

Include the (variable) profit generation as an output, to be the Performance Index. The calculation of cost and revenues will depend on consumption and production rates, and on unit costs and unit revenues which are included as Global Factors. It is possible to include equations other than just multiplications to represent total costs and revenues.

Carry on production with optimization while keeping updated the Global Factors, as often as they change to any significant amount.

This approach also enables more subtle adaptations for profit maximization, taking other combination of factors into account, such as maximizing profits by some balance between maximum yield and throughput.