

## How Best Practices in Control can help Sustaining Operational Excellence.

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### Abstract

In their strive for operational excellence, companies have to deal with many influences on their plant operation. These include changing operating conditions due to changes in planning, variations in the quality of raw materials, changes ambient conditions, and last but not least the impact of operator interventions. Relatively small differences in the way these disturbances are handled can have a big impact on the effect the disturbances have on longer term plant operation. Small temperature excursions in a reformer or a convertor can quickly lead to reduced catalyst activity and hence impact the long term runtime of a plant.

By applying best practices in automated control of Ammonia and Urea plants, producers are reducing the frequency at which excursions happen as a result of disturbances or sub-optimal operator intervention. These best practices range from optimized base layer controls to complete auto-pilots for the entire plant.

The paper discusses some of the most widely used best practices in automated control of Ammonia and Urea plants, and discusses some examples of the benefits from these best practices. The paper also discusses how companies adopt the best practices and related technologies.

### Operational Excellence – or not?

Walking into the control room, it's clear that the operation of the production facility is smooth and consistent. Key process parameters are constant and at their most optimal value. Operators monitor the operation of the unit, but they don't have to make any changes to the plant, as it is running according to specifications. It has been for a long time, and will be for many more weeks, months, years... Still, somewhere in the distance, an alarm sounds.

And then you wake up.

Clearly, this situation where the production units are running without any need for operators to make changes, and with no variability in the key process parameters, was a dream. In reality, the operation of Ammonia and Urea production units is continuously being affected by disturbances. These disturbances include composition changes of the feed and fuel gas (resulting, amongst others, in variations in the firing and conversion in the reformer), changes in ambient conditions (impacting for instance air compressor performance), sudden equipment failures, and suboptimal operator interventions (including too small, too large or untimely corrections to key setpoints and erroneous setpoint entry, or even "default" setpoints that get entered at the start of each shift). The extent to which each of these disturbances occur and lead to problems obviously varies from site to site, but each production facility suffers from such occurrences that disturb the normal operation.

The effects of these disturbances can be very significant. Temperature excursions can easily lead to accelerated catalyst deactivation, which impacts the runlength of the unit. Upsets in the front end of an ammonia or urea unit can result in significant variations in the H/N (ammonia) or N/C (urea) ratio, and these suboptimal ratios can impact the conversion for quite some time before the optimal ratios are restored. Operators making suboptimal changes to the key process parameter setpoints will inevitably drive the process away from its economic optimal operating point, leading to reduced efficiency and production rates. At a higher level, the impact of these disturbances is visible in key statistics like the number of unplanned outages, efficiency, and wear and tear of equipment.

Only some of the disturbances can be prevented. Needless to say, a thunderstorm cannot be prevented – it comes as it comes. Suboptimal operator interventions however can be prevented to a large extent. But whatever the type of disturbance, minimizing the occurrences and impact of the disturbances on the operation of the unit will significantly contribute to the reliability of operation. Minimizing the occurrences and effects of disturbances is therefore an important driver to sustaining operational excellence.

Process control and automation helps to minimize the impact of disturbances on the unit operation. Having the right process control in place provides a much faster response to the disturbances, a much more consistent response to the disturbances, a more economic response to the disturbances, and last but not least: optimal process control reduces the dependency on operator interventions to keep the unit operation within specifications. In short: optimized process control enables sustaining operational excellence by providing more stable and consistent operation.

Most ammonia and urea producers have recognized the importance of process control as an enabler for sustaining operational excellence. Yet, many are not taking the right steps to ensure that process control and automation is used to the extent possible. A significant step can still be made in increasing the contribution of process control to sustaining operational excellence. In making these steps, let's consider what best practices exist in process control and automation. Before we do so, let us distinguish between two levels of process control: base layer control, which resides in the DCS and provides the second-to-second control function for individual process parameters (flow controllers, temperature controllers, pressure controllers, etc), and Advanced Process Control or APC, which either resides in the DCS or communicates with the DCS, and acts as an auto-pilot for the plant, enabling operators and process engineers to specify limits and production targets, and then automatically controlling the plant to those targets within those limits, in a most economical way. The base layer controls are often referred to as "PID controllers", and the APC is often referred to as "robot operator", "plant auto-pilot", or "plant cruise control".

The best practices in this paper don't relate to technical details on how to control a specific key process variable, but focus on the way organizations adopt new technologies and embark on a road to optimize their process operation by improved process control.

## Best Practices in Control

Before going into detail on some of the best-practice aspects of optimizing process control and automation, it is important to discuss a few high level principles related to the subject.

1 - For companies to really optimize their process control and automation functions, companies need to have or define a vision on control. Such vision should define where the company wants to be in the future with respect to the level of automation and control, what the resources are that the company wants to spend or

deploy, etc etc. In the refining industry, many refiners have taken a visionary approach to control and automation, and have defined a roadmap towards their end goals.

2 – Before embarking on implementation of optimized base layer controls and/or advanced process control, clear, measurable success criteria need to be defined. Too often, PID loops are configured based on what is perceived to be “best practice”, but in reality the PID loop is kept in manual 100% of the time. Although the completed configuration work suggests that the job was done successfully, it’s clear that the work has not contributed to improving the operation. On the contrary: a loop that is in manual is not just worthless, it’s a hazard, as it might mislead people and make them believe that key process parameters will be controlled “when necessary”.

3 – In defining the “optimal control and automation”, plant differences need to be recognized and respected. There is no “one size fits all” solution. Every plant is different. Looking for a generalized solution will result in suboptimal control.

4 – Although the implementation of optimized base layer control and advanced control solutions can be phased, the end-result has to be pre-defined. Will the goal be to implement just an optimized base layer control? Will APC be added in the future? Is there a plan to deploy Real Time Optimization afterwards? The end result will dictate at least to some extent what the optimized control will look like. An optimal base layer control structure might look different with or without Advanced Process Control as a layered solution on top of it. This is simply due to the fact that APC might be designed to “take ownership” of handling specific disturbances in a more efficient way than a base layer control loop.

The above aspects are all too often forgotten when a company decides to optimize its control and automation. And in that case, significant improvements can still be obtained from optimizing the control and automation functions. But money is left on the table as the results might be suboptimal, if not all of the above aspects are taken into account.

Going one level deeper, let’s look at some of the best practice aspects of optimizing base layer controls. As we do this, there will be a high level of “common sense” in the discussions. Yet, experience tells us that many of these aspects are forgotten when control staff (internal and external) are given a mandate to start optimizing the base layer control structures.

## Optimal Base Layer Control – Best Practices

The first thing to keep in mind when looking to optimize the base layer control structures is that PID loops often have both a control and a safety function. In order to be able to optimize the control function, it might be necessary to separate the safety function from the control function (for instance by using override control structures). Such separation avoids the need to sacrifice control performance for a safety function.

The second important principle to remember is that PID controllers are by definition local controllers. They will, in general, control one process parameter with one process handle. Cross-effects between individual PID loops will generally not be “known” by either of the PID loops. Smart feedforward schemes can be applied which can significantly improve the performance of PID loops, but in the end, a PID loop controls one process parameter by manipulating one process handle. In control terms, this is called SISO (single input, single output). As the process is hardly ever this straightforward (every operator will confirm that changing one process parameter will affect many others at the same time), the extent to which PID loops can help control the process has its limitations.

Next, it's important to ensure that the base layer controllers are based on reliable and accurate instrumentation. PID loops using faulty or incorrect instrumentation normally introduce more problems than they can solve. Simple measures can sometimes be taken to improve the usability of measurements. For example, a noisy measurement can be filtered to make it usable for PID control.

In defining base layer control structures, make sure to recognize and respect the physics in the process. Understanding the process characteristics that need to be controlled is key to maximizing the positive impact a base layer controller can have on process stability and performance. Too often, a control challenge is looked at from a pure control engineering angle. Although the control problem can be solved nicely from a control engineering point of view, it remains to be seen whether that solution will actually improve process performance. A simple example is the control of a ratio of two gas flows. Controlling the ratio based on the straight flow measurements (or even the normalized flows) will be a great help to operators, and generally provide additional stability to the process. However, what is the ratio that is important to the process operation? Typically, this would be a ratio of two of the components in the streams. Converting the simple flow ratio to a ratio that represents the ratio of the important components will provide a lot more value to process stability and performance than the simple straightforward flow control. This is true even if the actual components in the flow need to be inferred due to absence of an analyzer.

Practical process limitations can override the choice for "normally applicable" control structures. If keeping a valve 100% open represents the most economical way of operating, then there is no point in configuring a PID loop that controls the flow through the valve. Operators will keep the loop in manual by default. If there is a stability issue in the particular part of the process, then the solution should be found using a different handle than the valve that should always be 100% opened.

A very important aspect is stability. In tuning PID loops, engineers often focus on performance. However, considering the working range of the PID loop, it is important to keep in mind that a stable loop today might oscillate tomorrow at a slightly different working point. Apart from the tuning aspect, some parts of a process simply won't allow for a stable PID controller, because of its inherent process behaviour. A good example of this in the refining world is a stabilizer reboiler furnace outlet temperature controller. Due to the partial vaporization that takes place inside the tubes in the furnace, the temperature in the return line to the column will not change if firing in the furnace is increased. Instead, it will stay constant for quite a while, and then suddenly increase significantly. Needless to say, this introduces instability, rather than improving process stability. Another example where stability issues are often overlooked is the control of top and bottom temperatures in distillation columns or bed temperature controllers in exothermic multi-bed reactors with quenches. It is often possible to configure and tune a set of PID controllers that perform well in a single, stable operating point. Very often however, due to the multi-variable nature of the process, these PID controllers will soon start to oscillate if slight changes or disturbances enter the process. This is simply due to the fact that PID controllers, as mentioned before, are SISO controllers, whereas the process they're trying to control is inherently multi-variable.

The seventh aspect to remember is that a new base layer control structure should solve a problem, and not just relocate a problem. A classic example of a situation where a problem gets relocated is an intermediate feed drum between two columns. The level controller of the vessel got retuned because the level was changing too much, which made the operators nervous. As a result of the retuning exercise, the vessel level was kept much more steady, so the problem of the fluctuating level got solved successfully. However, as a result, the feedflow to the second column is now varying a lot, which creates problems in the operation of the second column, putting product qualities off-spec. The control engineer solved the problem of a fluctuating level, but never actually solved the root cause, which was located upstream of the first column.

Summarizing, the process dictates to a very large extent what the optimal base layer control structure should look like. In many cases, it will look like there are multiple possibilities to solve one single control issue. Choosing the most elegant or most simple solution is unlikely to be the most optimal solution. Although simplicity is an important factor, the process side of things will have to be evaluated before the right decision can be taken as to which control structure will contribute most to process performance.

## Advanced Process Control – Best Practices

The potential contribution that Advanced Process Control can bring to sustaining operational excellence by reducing the impact of disturbances is different to the potential that an optimized base layer control brings. This is due to both the scope of APC as well as the fact that APC is inherently “slower” than base layer PID control loops. Although technically nothing stops APC applications from running on a second by second basis, doing this would create significant overlap between the (dynamics of) control functions of the base layer controllers and the APC application. Therefore, in practice, APC applications are running typically on a one-minute basis. Because of this, and because of some other (dynamic) characteristics of APC applications, the disturbances that APC applications can handle are of a different kind than the disturbances typically handled by base layer controllers.

The big added value from applying APC technology on top of an optimized base layer controller comes from three aspects. Firstly, APC applications are multivariable, which means that they are capable of considering the entire process including all its interdependencies. Secondly, APC applications are predictive, which enables them to look into the future to evaluate where the process is going, and decide not just based on the past but also based on the predicted future how the key process parameters need to be adjusted. Thirdly, APC applications have the capability to automatically steer the process towards its economic optimal point of operation, whilst ensuring that key process parameters stay within operator- or engineer defined limits. None of these functionalities can be implemented with just base layer control. Together, these characteristics of APC make that APC is capable of stabilizing the process significantly, beyond the stability that base layer controls can bring, and in addition generate benefits like up to several percent more throughput, up to a percent lower specific energy consumption, more constant product qualities, etc etc.

In evaluating whether to apply APC applications, and in designing them, there are several best practices that need to be remembered, in order to make the application of APC successful, and to let it contribute to the maximum extent possible to a better performance of the process.

In deciding whether or not to apply APC, it is important to evaluate whether the plant is “APC-ready”. A critical factor in determining whether or not a plant is APC-ready is that the critical instrumentation required for APC is present and functioning reliably and accurately. This requirement is however very often misunderstood to mean that “all possible equipment needs to be available and all possible equipment needs to function correctly”. This is not true. APC critical instrumentation is just a rather small subset of the equipment available on site. Sure enough, there are occasions where for instance temperature indications are not located at the right tray in a column, or an on-line analyzer is not available for a stream property that cannot otherwise be calculated. But in most cases a plant is “more ready than you think”. Remember that operators are currently running the plant. So one way or another there seems to be sufficient information available to allow them to run the plant. This makes the likelihood of the plant being APC-ready quite high.

Once it’s been decided that APC will be applied as a means to further improve the plant stability and performance, the scope of such APC application needs to be defined. This is not a trivial matter. The “easy way out” for many APC vendors is to simply say “oh well, the application needs to cover the entire plant”.

However, this is often not ideal from an ROI point of view. If the reformer is the main bottleneck of the plant, and the conversion section is relatively well-controlled with the optimized base layer controls, then obviously a small scope APC application just covering the reformer section would suffice, and provide the best ROI. Note that generally speaking, smaller applications are more easily adopted by operations personnel, so the best practice is to not overcomplicate the scope of an application. Having said that, not including constraints in the unit in order to minimize the scope (and cost) of an application will kill the application: acceptance will be very low and operators will switch the application off very soon, as they observe that the application does not take important constraints into account.

There's plenty of choices for APC technology; APC technology can be considered a commodity these days. However, some aspects need to be taken into account when picking the technology to use. Firstly, the technology should suit the purpose, and not be overly complicated. Generally speaking, APC applications in the fertilizer and syngas business are relatively small when comparing them to refining and petrochemical applications. This makes that simpler APC technologies can suffice. The lower the number of functionalities that aren't needed, the smaller the number of parameters that need to be specified in order to make the application do what it should do, and the lower the implementation and maintenance costs are for the application. Secondly, the technology should be low cost. With margins under pressure, the choice of technology should not imply a long term liability in terms of yearly license fees. Thirdly, the technology should allow for true economic optimization. Some technologies that are available on the market will stabilize the plant, but won't drive the plant to its economic optimum. Although the stabilization of operation in itself represents a significant benefit, a lot of money is left on the table by not economically optimizing the operation. Remember however that the technology is just the tool. A critical success factor for APC is the domain knowledge (specific ammonia and urea process know-how and operations experience) of the vendor staff that implement the applications.

Another best practice in applying APC is to focus on maximizing end-user acceptance from the start of the implementation. Typically, operators are wary at best when an APC implementation project is commenced. They don't believe that something abstract like an APC application can do their job, and some fear outright for their job security. End-user acceptance can only be achieved by building trust, and by enabling the end-users to actively use and manage the application. There are several aspects that will facilitate this acceptance. One aspect is to make the profit of the APC application visible to the operators. Some technologies allow a simple way of providing the operator with a "benchmark" profit (the profit potential) that could be generated by the APC application if the operator were to allow the APC application to run within pre-defined, "normal" limits. If the operator can compare that profit potential to the actual profit being generated by the APC application, it becomes very tangible what is being left on the table. The comparison provides a very good incentive for the operator to continuously look for opportunities to enable the APC application to "make more money". Beating the profit potential becomes a sport. Keeping all-time high scores becomes a game. Note that the profit does not need to be expressed in money; KPI's like specific energy consumption or simply throughput figures will provide great incentives as well.

Needless to say, training the operators on how the application is functioning, and on how they can manage the application, is the key to success. This is something that is best done during the commissioning phases of the control application, and in the first 6 to 9 months afterwards. If this optimal time-slot for training the end-users is missed, it will be very difficult to catch-up. The vendor plays a very important role in this training, although the local control engineer, who becomes the first point of contact for the operators once the vendor has finished the commissioning, needs to take part in the training as well. As a best practice, this training has to be more than a few hours of class-room training. Although class-room training can provide a base understanding of APC to the operators, nothing beats learning to manage the application whilst it's running live on the plant. Note that knowledge transfer to operators is best done in the context of a trust-

relationships, and therefore it is of utmost importance that the implementation project team has established such trust relationship with the operators during the earlier phases of the project.

Another aspect that facilitates user acceptance is pro-active mentoring. If an operator has switched off the application during his nightshift, go the extra mile to follow-up with him on what the reason was, and why he believed that the application didnot do the right thing. And more importantly: the fact that he switched the application off, but didnot switch it on again later, indicates that he sees limited value in having the APC application running. That needs to be addressed. The same holds for the all-too-familiar “clamping” of the application. Some organizations put pressure on operators to keep the APC application on, but the organization doesnot actively mentor the operators to enhance the acceptance of the application. In those cases operators will often clamp the application: they will put the low and high limits of key variables in the application very narrow, which means that the application is switched on, but it cannot perform any control or optimization action. In management KPI’s, the APC applications will show as a success because they’re ON all the time, but in reality, they add zero value.

Summarizing, APC can bring huge benefits, both economical (by increased throughput, lower energy consumption, etc) as well as by improving and sustaining operational excellence through improved stability and consistency of operation, but in deciding for APC and in deploying APC, it is important to take the above aspects into account.

## How Companies Adopt these Best Practices

As stated in the previous sections of this paper, it is important that the company has a vision with respect to the control and automation of its plant. Once such vision has been developed, the question then becomes how to move from the current level of control and automation to the visionary level. Different companies choose different roadmaps for this transition. These roadmaps can roughly be divided into four categories: the “deep dive” approach, the “cold feet” approach, the “layered” approach, and the “masterplan” approach. Each of these approaches will be discussed in a bit more detail here, together with their advantages and disadvantages.

In the “deep dive” approach, companies dive into the transition, defining numerous projects that will run in parallel and aim at getting to the visionary level of control and automation as quickly as possible, under the assumption that the quicker they get to the top level of control and automation, the higher the ROI will be. Although in principle this is often a true assumption, in reality this approach can introduce some (organizational) challenges. Firstly, the optimization of the base layer controls can be a resource-intensive activity. Depending on how MOC (management of change) procedures are handled within the organization, changes made to the DCS controls might require a significant involvement of local resources. Clearly, if lots of these activities are deployed in parallel at a larger site, resource constraints will become an issue. Secondly, if APC technology is new to the site, and it’s being deployed in a big wave of new applications across the site, adoption of the new technology might be an issue. In the context of “too many new things at once”, both control engineers and operators might be overwhelmed by what’s coming at them, and this might hamper adoption of the new technologies. Concluding, the “deep dive” approach can be an attractive road from an ROI point of view, but in order for this to be successful, organizational aspects need to be carefully assessed first.

In the “cold feet” approach, companies do the opposite as in the “deep dive” approach: they take very small steps, often defining very small projects one at a time. This approach means that with very limited resources, the entire transition can be achieved. Needless to say, the transition will take a very long time, and this might

not be ideal from an ROI perspective. If limited resource availability was the key driver for an organization to choose the “cold feet” approach, then the limitation in resource availability will eventually still become an issue in the transition. Optimized Base Layer Control structures and new APC Applications will require some maintenance, and more importantly, these require active mentoring of the operators by the control engineer(s). This mentoring and maintenance puts a load on the control engineer, and therefore, the more small projects have been done, the higher the load becomes on the control engineer, which limits the amount of time he can spend on new (small) projects. In reality, this means that the “cold feet” approach will be successful in the first few projects, but after a while the pace at which new projects get deployed reduces, and eventually the whole transition comes to a hold and the visionary level of control and automation is never reached.

In the “layered” approach, companies initiate major projects to optimize the base layer controls first, and only when this is done, they initiate projects to roll out APC technology on top of the base layer controls. This has been a very successful approach for many companies. The main advantage is that investments are staged, and since quite often optimized base layer controls will yield significant benefits, the second phase projects, which deploy APC applications, can be funded by the benefits from the base layer control optimization projects. Needless to say, the biggest disadvantage of the “layered” approach is that the time-to-benefits for the APC applications is relatively long, which means that the benefits from the APC applications will start later. As discussed in this paper, it is important to define the full vision on automation and control, prior to starting with the optimization of the base layer controls. Knowing that an APC application will be deployed on top of the base layer controls at a later stage, might influence the design decisions that need to be taken when optimizing the base layer controls.

Finally, the “masterplan” approach is an approach that most larger companies adopt when deciding how to transition from their current level of automation and control to their visionary level. In this masterplan approach, the company executes a detailed study which investigates the opportunities to improve automation and control on the different units at site. Detailed assessments are done to determine the benefits that can be obtained from improving the base layer controls and deploying APC applications. The scope of each APC application on each unit is carefully defined. The costs and resource requirements for the optimization of the base layer optimization for each unit and APC application on each unit are determined. Then, based on the planned availability of the production units, and based on a careful cashflow, NPV, and resource analysis, the priorities for each of the activities are determined. This so-called “masterplan” sets the order and timeline in which different control projects are to be initiated. Needless to say, the greatest advantage of this approach is the maximized ROI. By careful planning of resources and investments, the ROI is maximized across the company. The main drawback that keeps companies from adopting this approach is the investment required for the masterplan study. Although this detailed study is key to building the masterplan, the deliverables from this (often expensive) study activity is “just” a report, i.e. no direct benefits stem from the study activity.

As with any investment, defining the key success metrics upfront is very important. Examples in the APC section of this paper show that simple metrics like “APC switched ON” aren’t sufficient to guarantee a high ROI. Success metrics need to be directly related to the process performance and overall economics of the operation. If they aren’t, the success metrics won’t indicate high ROI.

Some companies have a choice to deploy APC technology with in-house staff or external vendor staff. Although it often looks financially more attractive to implement the APC applications with (trained) in-house staff, there is a risk related to it. The risk stems from the political context in which the in-house projects are initiated. If the performance of the new applications is below expectations, it is often more difficult to take a strong position towards the project team, demanding improvement actions. If the technology is deployed using external vendor staff, there is a clear vendor-client relationship in which a performance issue can be addressed and resolved.

Dedicated resources that are assigned with the responsibility to maintain the applications and function as the first point of contact for end-users, are absolutely required within an organization that embarks on the road to a visionary control and automation level. Only if the number and complexity of control applications within the organization is very high, a fully outsourced maintenance and support model can be justified. This is however seldom the case in the fertilizer and syngas industry. Therefore, it is important to have a clear view on which department in the organization will take ownership of the applications. One of the lessons learnt for many companies is that the staff who own the application do not just need to be skilled in IT, automation and control, but more importantly they need to have a thorough understanding of plant operation. Questions from end-users (operators) are hardly ever related to software or other IT related aspects of the application. The questions will almost always relate to process operation aspects. In order for the owner of the application to be able to answer these questions, this person needs to have a thorough understanding of process behaviour and practical process operation. Note that with a larger install base of APC applications, it may become justifiable to deploy automated performance monitoring. For the base layer controls, this is more frequently done, with good results.

Concluding, different companies take different approaches to making the transition from where they are today with respect to control and automation, to where they want to be. As long as their choice for the road to their visionary level is based on a well-thought decision, the transition can be successful with any of the described roads.

## Conclusions

Since optimized base layer controls and APC applications significantly improve the stability and reliability of plant operation, they can be an important contributor to improving and sustaining operational excellence. In order to maximize the positive impact of these applications on sustaining the operational excellence, several best practices need to be taken into account in defining and deploying the projects to improve the base layer controls and to implement APC applications. The most important aspect is to have a clear vision of where the company wants to be with respect to control and automation. Without such vision, choices on which projects to deploy and when to deploy them are likely to be suboptimal, leading to lower-than-desired ROI's. But if done right, the potential contribution to improving and sustaining operational excellence from these projects is huge, thanks to the improved stability of operation, more economical plant operation, and reduced dependency of operator interventions.