Executive Summary
In modern process manufacturing plants the correlation between the performance of the process control assets and the financial performance of the business is strong. Virtually every advanced process control project has been justified using predictions of improved business performance resulting from improved control. The process of implementing such projects routinely includes improving the performance of the regulatory controls and in some cases instrumentation. This paper will focus on the following question: "Among all of the control assets in the plant, where should maintenance resources be expended in order to have the most significant impact on plant performance?"
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**Current Maintenance Approaches**

Due to the sheer number of assets, plant staff is challenged to maintain large numbers of regulatory control assets and a growing number of MPC applications. In most organizations today, a combination of failure-based and scheduled preventative based maintenance techniques is used in maintaining plant control performance.

A failure-based maintenance approach is one where the control asset is left un-maintained until one or more failure modes have been observed. As examples, for the regulatory loop, the failure may include valve or sensor problems, improper tuning or disturbance problems. In a worst-case scenario, if the loop is causing significant difficulty for the operator it may be taken out of automatic control and placed in manual until corrective maintenance can be applied. Under this model, maintenance technicians and engineers respond to high-priority operator complaints in a “fire-fighting” fashion.

A preventative maintenance approach involves regularly visiting each asset, assessing its performance and applying necessary maintenance to ensure it continues to perform optimally. In practice, most facilities have mature preventative maintenance programs. Critical loops and applications tend to be fairly well maintained as they receive the majority of the control engineer or maintenance technician’s time, while others are maintained on a less frequent schedule if at all. As described, in most plants, the numbers dictate that fire-fighting is all but impossible.

Recognizing the obvious weaknesses of these maintenance strategies, many companies have adopted a condition-based approach to maintaining their plant controls. A condition-based maintenance (CBM) program employs a control performance assessment and monitoring application which detects control performance problems at all levels of the plant control hierarchy, from control valve to MPC application. Based on the health or condition of the asset, appropriate engineering, maintenance, and operations personnel are alerted to problems and are able to more effectively address control related problems.

With a CBM approach, significant benefits have been reported by many companies worldwide. As examples, Eastman Chemical reported a 53% reduction in off-class production due to process control related issues \(^1\) while Marathon Ashland Petroleum reported a 500 bbl/day increase in throughput on their crude topping unit \(^2\).

Other, less tangible benefits reported include:
- Performance of all plant controllers and applications can viewed and those needing attention are flagged automatically
- Visibility of the problem by all those associated with maintaining and supporting the plant controls is improved
- Reduction in maintenance costs associated with a given level of plant performance as the work process of maintaining the plant controls and applications is streamlined
- Reduced number of alarms and controller interventions by operation staff

**Challenges and Revelations**

Over the past several years control performance assessment and monitoring technology has improved. The challenges are no longer related to whether the technology itself is effective, but rather related to the human factors surrounding the use of these applications. How an application integrates with existing work practices and maintenance procedures is the critical success factor. If the application is truly monitoring all plant control assets, a tremendous amount of information is generated from huge volumes of plant data. Key to the success of these applications is in the ability of the application to allow the user to quickly identify where to direct his or her attention. Keeping in mind a single application may be monitoring upwards of 3000 regulatory controllers, a dozen plant analyzers, online inferential models and 10 or more MPC applications, the important question becomes:

“Among the poorly performing control assets, where do individuals focus their time?”
Earlier versions of control performance applications generated reports on individual controllers or applications, but required users to access performance measures and reports using a tree hierarchy that mimicked the plant hierarchy to organize the assets and required the user to drill in on individual controller performance reports to successfully troubleshoot problems. Such an interface is shown in Figure 1.

![Figure 1 - Tree-View of Control Assets](image.png)

Though effective, users complained that finding problems with this method was inefficient. They needed a user interface that quickly directed them to important problems.

The issue here is not unique to this application, but rather is common to many automatic monitoring problems. E.R. Tufte, in *Envisioning Information* (Graphics Press, 1990) described the problem best:

> “…at every screen are two powerful information-processing capabilities, human and computer. Yet all communication between the two must pass through the low resolution, narrow-band video display terminal, which chokes off fast, precise, and complex communication”

In short, people can only act on information once it has been squeezed through the computer interface. This problem is compounded in complex monitoring solutions where there are several performance criteria. With the integration of several different classes of assets in a single system, such as with control assets, the user can be presented with an unmanageable set of independent problems to address. Prioritizing among assets becomes impossible.

To overcome these limitations, it is necessary to deliver the following functionality:

1. A consistent view of different classes of asset that permits the user to prioritize across assets (i.e. regulatory loops, MPC applications, analyzers, online estimators)
2. A high-information-density display that allows users to make visual comparisons among assets. As Tufte puts it, *“Comparisons must be enforced within the scope of the eyespan, a fundamental point occasionally forgotten in practice”*
3. An interface that enforces the appropriate workflow, presenting problems to users requiring user action and follow-up, and supporting that action. Figure 2 shows a simplified condition-based maintenance workflow. It clear from Figure 2 that the system must present the user with the information required to prioritize, confirm diagnosis and schedule maintenance.
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Tree Mapping Technology as a Means of Visualizing Control Performance Problems

Tree mapping technology has been identified as an effective means of solving the visualization problem. Tree mapping facilitates visual comparison by presenting a vast amount of information in a single display. Simple controls allow the user to change the display criteria and filter the set of data viewed. It is possible to view all monitored assets in a large installation in a single screen, thus circumventing the need for "drill-down" and making it possible to prioritize across an entire site.

Control Performance Monitor takes advantage of tree mapping technology to provide an information-abundant visual interface that allows users to monitor and assess all of a facility’s control assets in a single view. Control Performance Monitor is Powered by Matrikon, which represents vendor neutrality. This product works with third-party control systems and applications. Rather than depict control assets as a text list, tree mapping technology uses shape, size, color and grouping of geometric shapes to impart key performance information related to individual control assets.

Data is presented on all the control assets in a given plant with user-configurable views of key performance statistics such as: service factor, oscillation strength, relative performance index, number of user interventions, number of alarms, and valve stiction. The treemap makes it possible to easily spot controllers that are performing poorly among thousands, then zoom in on a group or hover the mouse over a single asset for more detailed information.

Application of Tree Mapping to Condition-Based Maintenance

Figure 3 below shows a treemap of the performance of 817 regulatory controllers on a single screen. In this Operational Insight web page, each controller is represented by a single rectangle, and controllers are grouped by process unit as denoted by the blue/grey border. In this particular view, the size of the rectangle for the controller is determined by the number of operator interventions, and colored by the controller’s performance (RPI – Relative Performance Index) while it is active. Controllers that were never active are shown in grey. The user can change the selection criteria using the drop down boxes at the top, and can apply filters shown at the right.
The advantages of this type of presentation are obvious, as the human eye is automatically drawn to the largest and most colorful objects. As the computer screen real-estate and color are allocated based on the filters selected, users can very rapidly identify problems among all the controllers on the site without spending valuable time searching for problems. The controllers generating the greatest number of alarms in this example show up as the largest rectangles on the screen, while the colors represent the RPI (relative performance index) statistic calculated by Control Performance Monitor.

Rectangles that are red, for example, indicate controllers that are settling either much faster or much slower than their prescribed benchmark. Conceptually, large red blocks denote controllers that require attention, while small green blocks represent controllers that are performing well and can be ignored by the user. Both the size and color filters are user adjustable and can be set for several of the key performance indicators Control Performance Monitor calculates – (service factor, operator interventions, oscillation strength, Harris Index, valve stiction, etc.) providing maintenance, operations and engineering with several different views of the same dataset.

Several of the key performance measures calculated for a particular controller can be viewed simply by passing the mouse over the individual rectangles, quickly getting users to the information they require, as seen in Figure 4.
Additional actions are initiated from the menu that pops up when the user clicks on the controller. In this implementation, users can view a detailed diagnostic report (Figure 5) where additional controller performance details are provided. This display helps the user confirm or refute the diagnosis as well as the initial priority set for the specific controller.

The tree mapping technology employed in Operational Insight allows users to visually determine the priority of fixing an asset relative to others. Additional maintenance work processes can then be initiated, such as creating a maintenance work order. After scheduling the asset for maintenance, the system continues to track performance, but does not alert the user of ongoing performance problems until the scheduled date for maintenance has passed. This process facilitates the condition-based maintenance workflow shown earlier in Figure 2.
Application of Tree Mapping for the Condition-Based Maintenance of APC Applications Definition

The power of tree mapping is that it permits the user to view a large quantity of information from many assets simultaneously. It is simple to present all of the APC applications in a plant, or even an enterprise, within a single screen, as can be seen in Figure 6, below.

Here, nine MPC applications across three units of a typical refinery are shown. Again, the size and color filters allow users to quickly identify issues with constraints, service factor and model performance, problems commonly experienced with CMPC applications. These summary views are excellent for a quick inspection of the status for a group of applications like the ones above.

Treemaps complement the traditional tabular views of data seen in more detailed reports. Tabular views of the data are preferred for a small number of monitored items, where there are several measures per item. Again according to Tufte, “tables usually outperform graphics in small data sets of 20 numbers or less” ([4]). One strength of tables is their ability to display exact numerical values. For that reason, tables are used to show detailed information more precisely than can be accomplished in a treemap.

Figure 6 - MPC Summary Treemap
The treemap is even more effective for examining the performance of the controllers in detail. It is possible to view all of the CVs (Controlled Variables), MVs (Manipulated Variables) or DVs (Disturbance Variables) for all APC applications in a single display, as can be seen in Figure 9 below. In this example, the CVs are shown grouped by APC application, the sizes of the boxes are determined by the percent time the CV is outside its limits, and the colors are determined by the model quality for the CV. It is simple to see from the figure that two APC applications have significant limit violation issues: 01ATM_MPC and 14RX_MPC. It is also clear that model performance underlies much of the problem. Using a hierarchical tree interface as was shown in Figure 1, a minimum of four web page views (plant, unit, MPC application, CV’s) would be required to draw a similar conclusion. The treemap exposes this information immediately. Unlike navigation trees, which become more cumbersome as items are added, the power of a treemap increases with the number of monitored assets. Figure 7 shows nine MPC applications with a total of 89 CVs.

![Figure 7 - Controlled Variable Treemap](image)

From this view, users can drill into a single CV to confirm the problem revealing a set of trends showing the behaviour of the CV in detail over the analysis period. In a similar manner, associated tree maps and reports detail MV and DV performance. Process by which alarms are engineered, monitored, and managed to ensure safe, reliable operations

Conclusions

The issue of control performance is one that is well known in the process industries. Modern monitoring technologies for control assets are transforming the control maintenance model from either preventative or failure based to condition based. Experience to date with control performance monitoring technologies in process industries has been generally positive, with recent industrial feedback bringing focus to a significant area for improvement – visualization of important results.
Finding the Needle in the Haystack: Visualizing Control Performance Problems

Information density is a significant problem for any CBM application where large numbers of assets are monitored. These applications assist in the control maintenance work process by transforming volumes of data into valuable performance and diagnostic metrics for individual assets, but as a large-scale plant may have in excess of 2000 regulatory controllers and ten or more MPC applications, finding the highest-priority problems can be challenging. Users do not typically have the time to search for information, yet common interfaces for such applications require users to search through lists of assets arranged in a tree-like hierarchy. This reduces the effectiveness of the condition-monitoring tool.

Treemaps flatten the tree hierarchy, displaying key information from each respective leaf on the tree. This allows users to see far more information in context than has been previously possible, permitting hundreds or even thousands of monitored assets to be viewed simultaneously. Users can quickly spot, diagnose and prioritize performance problems, expediting the entire control maintenance work process. Applications of tree mapping for both regulatory as well as APC monitoring and diagnosis have been illustrated in a refinery setting.

References