Finding the Needle in the Haystack - an Innovative Means of Visualizing Control Performance Problems

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Abstract

Process control performance is a cornerstone of operational excellence in the refining and petrochemicals industry. Control performance assessment and monitoring applications have become mainstream in the refining industry and are changing the maintenance methodology surrounding control assets from predictive to condition based. The large numbers of these assets on most sites compared to the numbers maintenance and control personnel has made monitoring and diagnosing control problems challenging. Identifying specific control issues on a refinery wide basis which are causing problems can be like finding a needle in a haystack. Tree Mapping, a data visualization technology developed in 1990 has now been applied to this problem successfully within a condition based maintenance framework. This paper explores the challenges associated with control performance assessment and monitoring and shows how tree mapping technology eases the visualization challenge associated with monitoring hundreds or thousands of control assets. Both regulatory and APC examples are demonstrated.

1 Introduction

In modern refining and petrochemical complexes 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.

For the purpose of this discussion, consider the plant control hierarchy (assets) as multiple layers of equipment and technology including: primary sensors including plant analyzers, end devices (valves, drives, dampers), regulatory controls and advanced control applications such as model predictive control and their associated inferential models. This contains more layers than the standard Purdue Reference Model (PRM) functional hierarchical computer control structure [11], because it is necessary to show the dependencies among the different components of Levels 2 and 3 of the PRM.

Figure 1 - Plant Process Control Hierarchy

Each device in the plant process control hierarchy impacts the bottom line performance of the unit to which it is associated as its performance degrades. Several authors including these two have documented the root causes of poor control, its effects and ultimate costs to the associated business. [1] [2]. These papers discuss the technical, human and business challenges associated with sustaining the performance of process control assets in modern refining and chemical complexes. This paper assumes that the challenges associated with sustaining the performance of these assets are well understood by the reader and rather than reviewing this material we attempt to bring focus to 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?" New technology is presented which addresses the data visualization problem associated with looking at performance measures from large Model Predictive Control (MPC) applications in addition to hundreds or even thousands of plant regulatory controls.

Current Maintenance Approaches

Due to the sheer numbers of assets, plant staff remain challenged to maintain large numbers of regulatory control assets and a growing number of MPC applications. In most refining organizations today, a combination of failure-based and scheduled preventative based maintenance techniques is used in maintaining the 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, disturbance problems, and others. 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 based 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 that fire fighting is all but impossible.

Recognizing the obvious weaknesses of these maintenance strategies, many refining and chemical companies have now 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. Significant benefits have been reported by many companies. As examples, Eastman Chemical reported a 53% reduction in off-class production due to process control related issues [3] while Marathon Ashland Petroleum reported a 500 bbl/day increase in throughput on their crude topping unit [2]. Financial benefits have been reported by many refining and chemical customers are world wide. Other, less tangible benefits reported have been:

- 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

3 Challenges and Revelations:

Over the past several years control performance assessment and monitoring technology has improved. In our opinion, 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 critical success factor. If the application is truly monitoring all of the 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 2-4000 regulatory controllers, a dozen plant analyzers, online inferential models and 10 or more MPC applications, the important question becomes: "Among the poor 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 (plant-unit-controller) 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 2

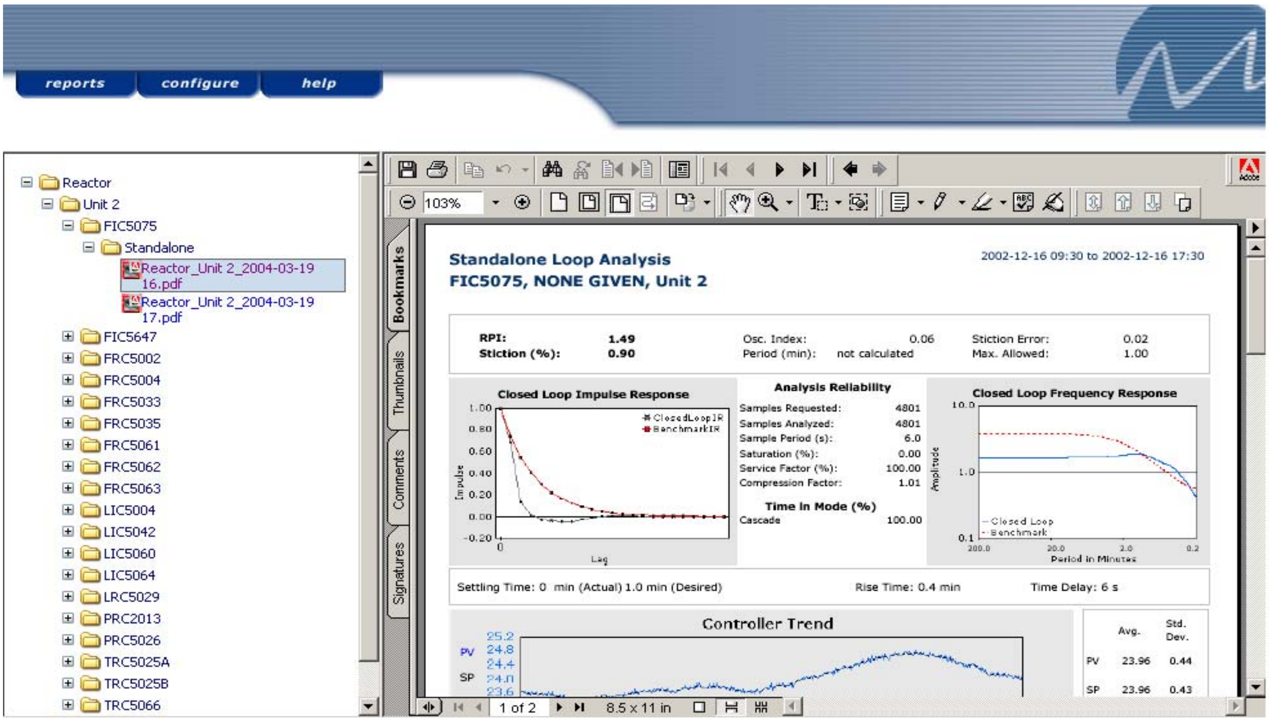


Figure 2 - Tree-View of Control Assets

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. Perhaps the best description of the problem is by Tufte [12]:

> "…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 with 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, we have found it necessary to deliver the following functionality:

1. A consistent view of different classes of asset, that permits the user to prioritize across assets (ie. regulatory loops, MPC applications, analyzers, online estimators)
2. A high-information-density display, that allows users to make visual comparisons among assets. "*Comparisons must be enforced within the scope of the eyespan*, a fundamental point occasionally forgotten in practice" (Tufte's emphasis). Tufte [12],
3. An interface that enforces the appropriate workflow, presenting problems to users requiring user action and follow-up, and supporting that action. Figure 3 shows a simplified condition-based maintenance workflow. It clear from Figure 3 that the system must present the user with the information required to prioritize, confirm diagnosis and schedule maintenance.

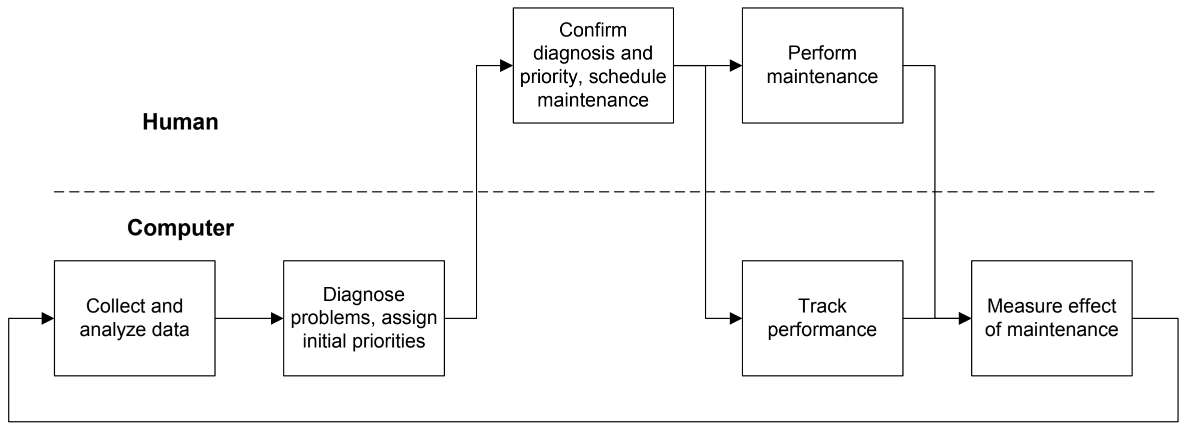


Figure 3 - Condition-Based Maintenance Work Cycle

4 TreeMapping Technology as a Means of Visualizing Control Performance Problems

In our efforts and investigation to solve the visualization problem, we identified tree mapping technology as an effective means of solving our 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 of the 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.

ProcessDoctor takes advantage of tree mapping technology by using it 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. Rather than depict control assets as a text list, treemapping technology uses shape, size, color and grouping of geometric shapes to impart key performance information related to individual control assets.

Tree mapping technology was initially developed by Dr. Ben Shneiderman, a professor of computer science at the University of Maryland, who created an application in 1990 to track the utilization of a hard drive shared by 14 users. Shneiderman's work revolved around creating interfaces that present large quantities of data simultaneously in a way that allows users to quickly detect and recognize relevant information and patterns [15].

ProcessDoctor's tree maps present data 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.

4.1 Application of Tree Mapping for the Condition-Based Maintenance of Regulatory Control Assets

Figure 4 below shows a treemap of the performance of 817 regulatory controllers on a single screen. In this ProcessDoctor 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 controllers 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.

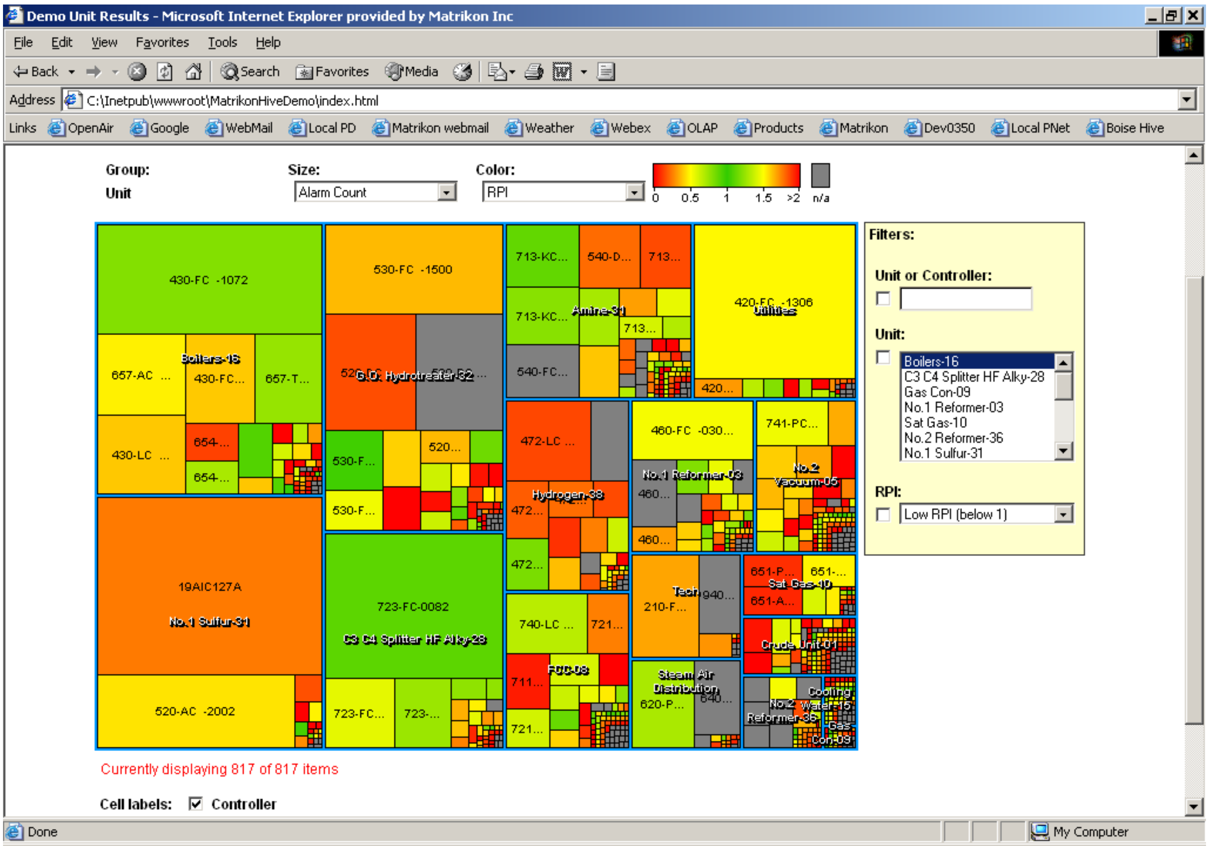


Figure 4 - Tree Map of Regulatory Control Performance

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 color spectra represent the RPI (relative performance index) statistic calculated by ProcessDoctor. Rectangles that are red for example indicate controllers that are either settling much faster or 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 ProcessDoctor 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 - Figure 5.

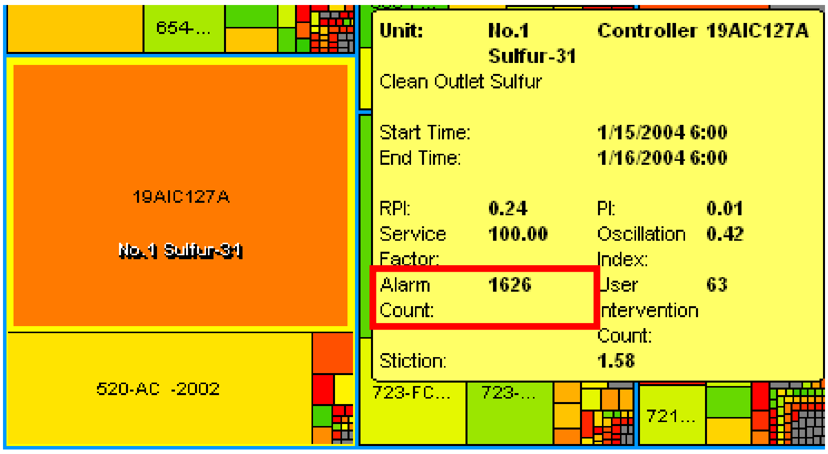


Figure 5 - KPI view of Controller 19AIC127A

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 where additional controller performance details are provided – Figure 6. This display helps the user confirm or refute the diagnosis as well as the initial priority set for the specific controller.

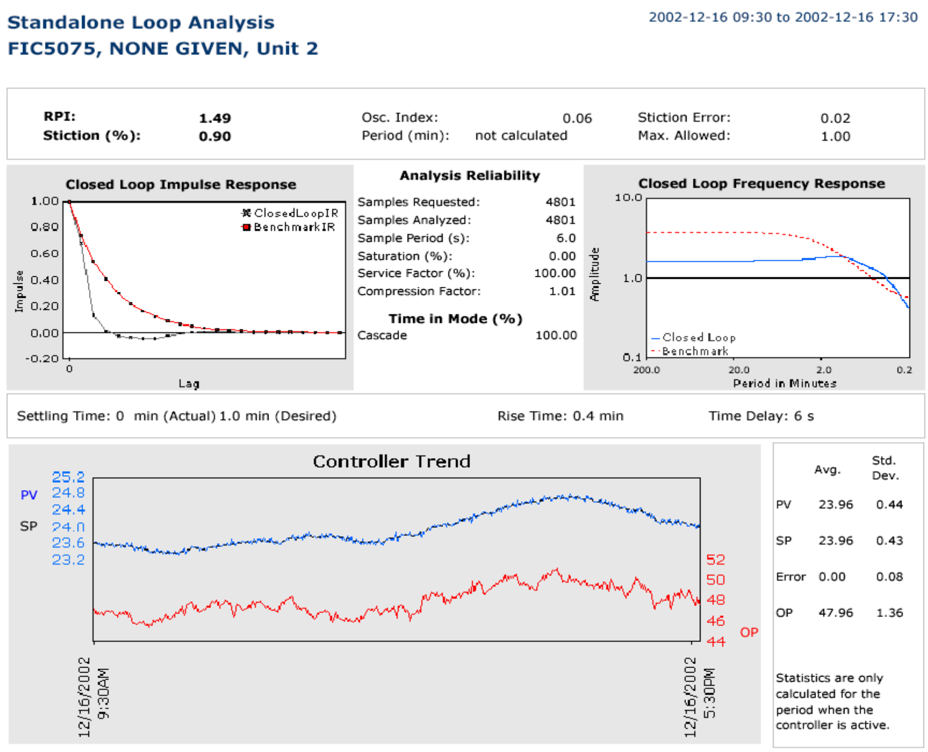


Figure 6 - Detailed Diagnostic Report for FIC-5075

The tree mapping technology employed in ProcessDoctor allows users to visually determine the priority of fixing an asset relative to others. Additional maintenance work processes can be initiated from this interface, such as creating a maintenance work order or annotating the result if desired. User may then schedule maintenance using a screen similar to the one shown in Figure 7.

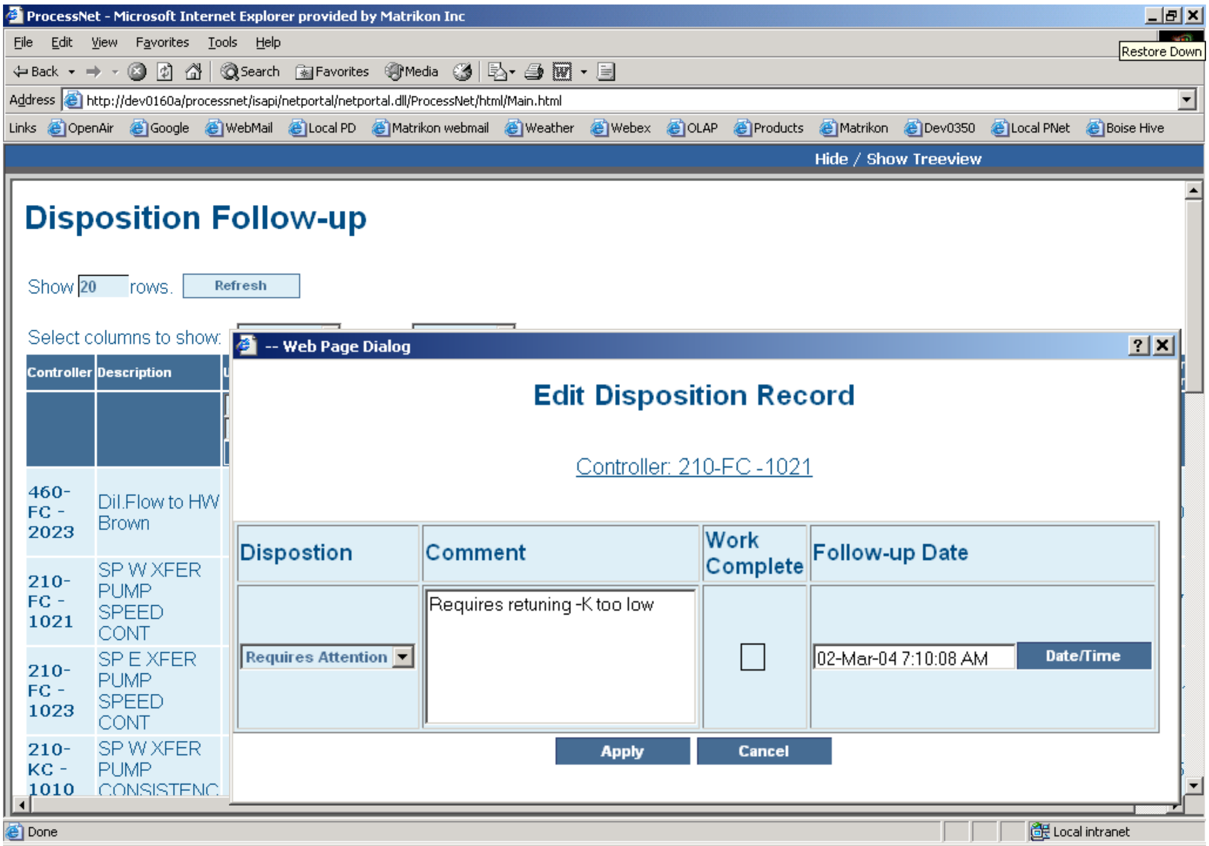


Figure 7 - Maintenance Scheduling View

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. ProcessDoctor facilitates the condition-based maintenance workflow shown earlier in Figure 3.

4.2 Application of Tree Mapping for the Condition-Based Maintenance of APC Applications

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 8, below.

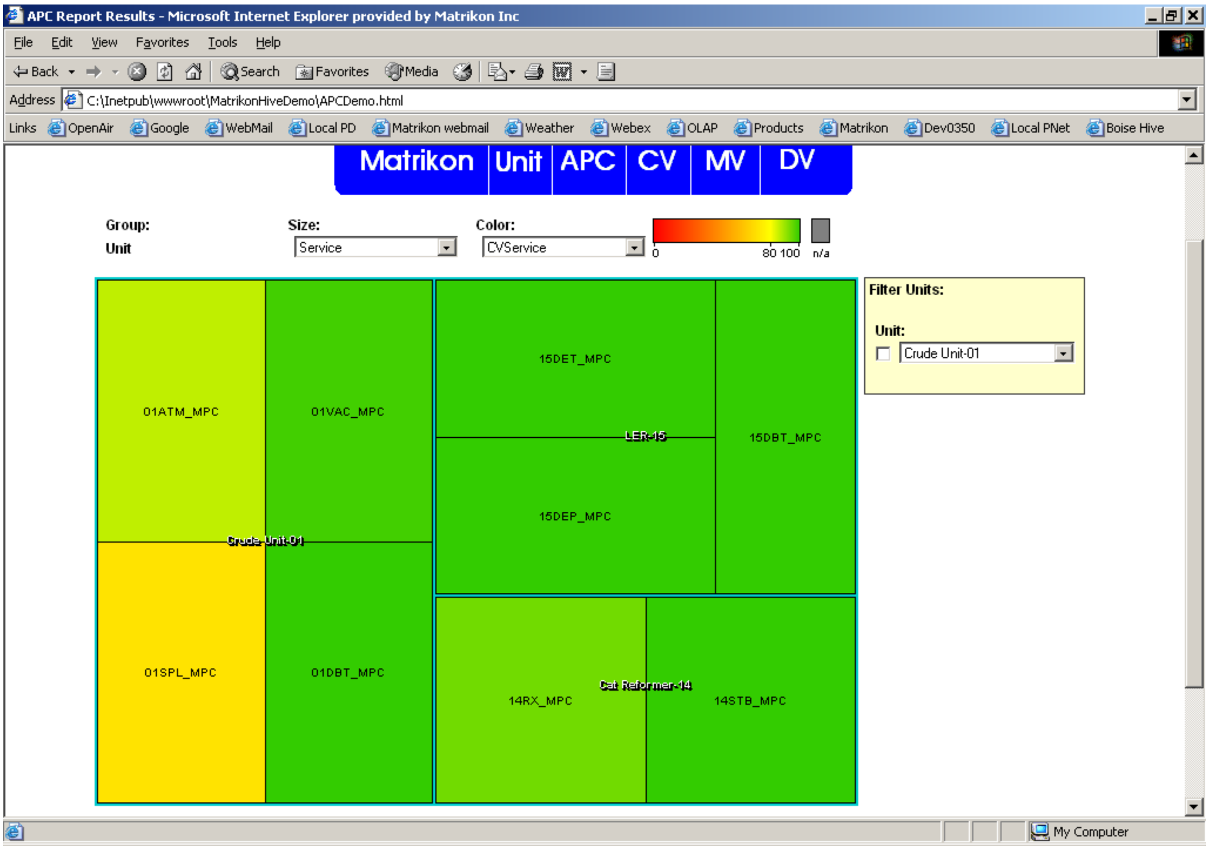


Figure 8 - MPC Summary Treemap

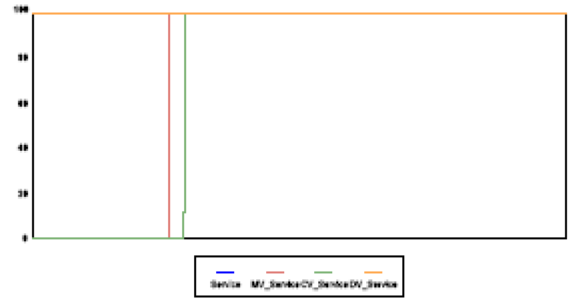
Here, 9 MPC applications across 3 units (Crude, LER, Cat Reformer) are shown. Again, the size and color filters allow users to quickly identify issues with constraints, service factor, and model performance, problems commonly experienced with CMPC applications. These summary views are excellent for a quick inspection of the status for a group of applications like the ones above. Tree maps complement the traditional tabular views of data seen in more detailed reports as seen in Figure 9, below. Tabular views of the data are preferred for a small number of monitored items, where there are several measures per item, as in Figure 9. Tufte [14] states that "tables usually outperform graphics in small data sets of 20 numbers or less" and that one strength of tables is their ability to display exact numerical values. For that reason, tables are used for drilldown showing detailed information more precisely, than can be accomplished in a tree map.

ProcessDoctor *online* — APC Performance Monitoring Report

Splitter

3/5/2004

Controller Utilization



Controller Information

Department:	Crude Unit -01
Sample Interval:	1 Minute
Weight:	1

Controller Daily Summary

Service%	MV Service%	CV Service%	DV Service%	Opt Service%	Opt Eff Service%	%MV Limit Tracking	%CV Limit Giveup	MV RPI	CV RPI	Model Index
100	74.4	71.4	100	100	92	50.6	4.14	0.88	0.72	0.59

Controlled Variables

	Service Factor	Effective SF	%Time Opt	%Limit Violation	%Limit Tracking	RPI	Model Index	OSI	Period	Alarms	Operator Interaction
01CC459	100	100	100	0	0	0.95	0.98	0.1	3.8	0	0
01FC492	100	100	100	0	0	0.59	0.82	0.2	1.4	1	0
01FC481	100	100	100	23	19	0.46	0.76	0.14	25	6	0
01FC459.OP	0	0	0	0	0		-0.31	0.7	18	0	0
01DP400	0	0	0	0	0		0.18	0.81	27	0	0
01TI459	100	100	100	0	0	0.76	0.93	0.54	17	0	0
01CC473	100	100	100	6	2	0.87	0.82	0.1	2.1	4	0

Manipulated Variables

	Service	Effective Service	%Time Opt	% Time Limit Tracking	At Movesize Limit %	RPI	OSI	Period	Alarms	Oper-Action	Prior-ity
01TC437	0	0	0	0	0	0.92	0.13	1.2	0	0	1
01PC420	100	100	100	32	4	0.91	0.06	4.2	3	0	1
01TC478	100	0	100	100	0	0.89	0.14	3.6	0	0	3
01FC459	72	45	100	21	0	0.79	0.07	2.7	0	9	2
01TC487	100	0	100	100	0	0.89	0.19	3.4	0	0	2

Disturbance Variables

	Service	OSI	Period	Alarms	Operator action	Priority
01FC301	100	0.11	4.1	0	0	2
01TI302	0	0.81	27	0	0	1

Figure 9 - Tabular APC Detail Report

The tree map is even more effective for examining the performance of the controllers in detail. It is possible to view all of the CV's (Controlled Variables), MV's (Manipulated Variables) or DV's (Disturbance Variables) for of all of the APC applications in a plant in a single display, as can be seen in Figure 10 below. In this example, the CVs are shown grouped by APC application, the size of the boxes are determined by the percent time the CV is outside its limits, and the colour is 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 2, a minimum of four web page views (plant, unit, MPC application, CV's) would be required to draw a similar conclusion. The tree map exposes this information immediately. Unlike navigation trees, which become more cumbersome as items are added, the power of the treemaps increases with the number of monitored assets. Figure 10 shows 9 MPC applications with at total of 89 CVs.

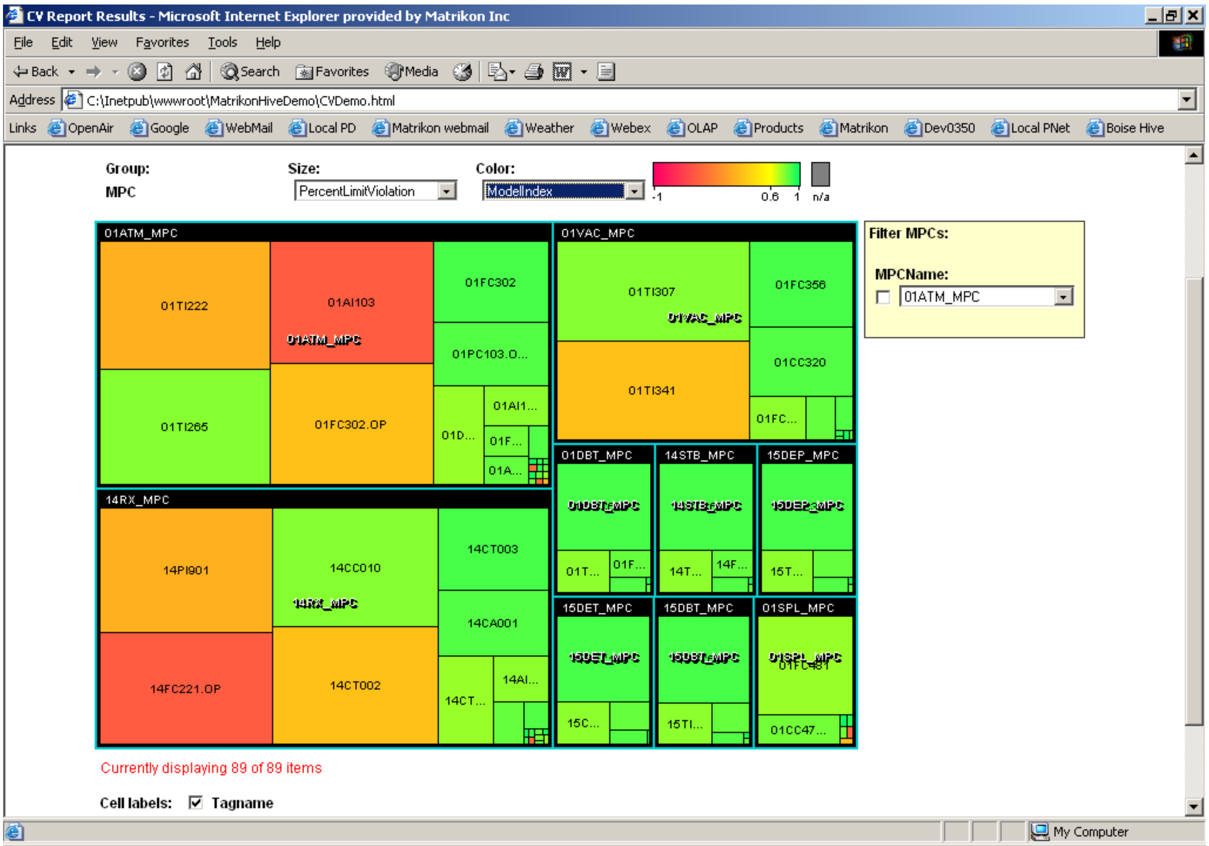


Figure 10 - Controlled Variable Treemap

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 - Figure 11.

Figure 11 - CV Details Accessed from Treemap

In a similar manner, associated tree maps and detailed reports analogous to Figures 10 and 11 detail MV and DV performance.

5 Conclusions

The issue of control performance is one that is well known in the refining industry. Modern monitoring technologies have emerged for control assets which are transforming the control maintenance model from either preventative or failure based to condition based. Experience to date with control performance monitoring technologies in refining has been generally positive, with recent industrial feedback bringing focus to a significant area for improvement – visualization of important results.

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 world-scale refinery may have in excess of 2000 regulatory controllers and 10 or more MPC applications, finding the highest priority problems can be challenging. Users report they do not typically have the time to search for information, yet common user interfaces for such applications require users to search through lists of assets arranged in a tree-like hierarchy. This is time-consuming and can be frustrating for the user, often reducing the effectiveness of the condition-monitoring tool. Tree maps flatten the tree hierarchy displaying key information from each respective leaf on the tree. This allow 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.

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