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Control loop performance monitoring – ABB's experience over two decades

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Abstract: When process control systems do not perform as they should, plant personnel will not obtain positive results and may even give up using some control loops entirely. To increase productivity and efficiency it must be ensured that the control system is used effectively. The best way to do this is to turn the automatic control on and to tune it correctly. This paper describes the expertise in control loop performance monitoring gathered by ABB's control experts. With more automated production processes and fewer experts, control loop performance monitoring (LPM) needs to be able to evaluate one hundred loops at a time instead of loop-by-loop analysis. This cannot be done with training or manual tools. In this paper, ABB's perspective on loop performance monitoring as well as several novel features is described. Finally, further research directions are highlighted.

Keywords: Control loop performance monitoring, PID control, industry automation, process control, chemical industry, paper industry.

1. INTRODUCTION

Process automation regulates the dynamics of an industrial production process to ensure safe and efficient production. One key aspect of automation is process control which in industry today is realised by PID control. The majority of regulatory control is installed and tuned during the commissioning phase, that is, shortly after the construction of the production facility. These are hundreds if not thousands of PID control loops. Many plants purchase an automation package and, once in place, believe it can run indefinitely, without intervention. But control systems do not run themselves. They are made up of computers, controllers, monitors, firmware, software and hardware. If, for example, an engineer ignores a fan, a controller can overheat and result in an entire portion of a plant being shut down.

The performance of regulatory control usually deteriorates over the lifetime of a plant because equipment ages and process dynamics change. In the course of time, continuous plants are not used as intended because the product changes or the production volume varies. This new objective of increased flexibility in production is addressed in initiatives such as Industrie 4.0 or smart manufacturing.

Deteriorating overall process performance leads to the need to assess the performance of control loops and answer the following questions:

- Are the controllers performing as expected?
- Are the actuators and sensors doing their job?
- Are there any faults in the process?
- Is any equipment malfunctioning?

Once a poorly performing control loop has been identified it is necessary to diagnose the problem and pinpoint the root cause. Ideally, the root cause should be definite and translated into a maintenance notification and suggested actions.

Often the degradation of performance occurs gradually. The impact of degradation is not felt straight away and the process will continue operation, if at decreased efficiency. However, if process equipment fails the resulting downtime usually causes dramatic cost. Many production companies today move towards predictive maintenance to avoid unexpected shut-downs. In predictive maintenance the condition of equipment, for example control loops, sensors and final control elements, is monitored and maintenance actions are carried out according to the results before the fault occurs.

Modern plant control systems integrate tightly with industrial equipment such as motors and drives or sensors. As a result, a control system includes far more elements than ever before. If any area falls short or fails, a site will experience production or quality variability that has a direct impact on plant performance. This makes it even more critical that automation control loops are checked and calibrated regularly.

Cost pressures have led many producers to reduce process engineering staff that might perform these services in-house. In many advanced economies workers in industrial production facilities are getting older, and many years of process expertise is being lost to retirement. As a result, plant personnel is responsible for a wider range of more complex tasks, reaching from operations to maintenance and including control, process engineering and software solutions.

Monitoring control loops requires a sophisticated skill set, including the fundamentals of control, knowledge on

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electrical and process equipment as well as detailed process understanding. Today and in the future there will be fewer trained personnel. Thus, the diagnostic results of control loop performance analysis have to be generated automatically and must be easy to understand.

In this paper we will investigate loop performance monitoring (LPM) from an industrial perspective and describe ABB's workflow and a solution called ServicePort. The relationship to other performance measurement areas in production such as maintenance, asset management and efficiency studies are drawn in Sec. 2. Sec. 3 describes some of the novelties in LPM that have been implemented in ABB's solution.

1.1 Loop performance monitoring literature

Systematic assessment and monitoring of the control loop performance has attracted interest in the academic community since the advent of digital control in process plants. General problems of control loops were reported in the 1990s (Bialkowski, 1993; Ender, 1993). Indices to assess the performance of control loops were developed, famously by Harris (1989) and addressing data signatures such as oscillations (Hägglund, 1995; Thornhill and Hägglund, 1997) as well as common hardware problems such as valve stiction (Horch, 1999).

Over the following decades, data-driven and model-based algorithms were developed and several reviews have been published that provide a comprehensive list of methods in control loop performance monitoring for single and multivariate control loops (Qin, 1998; Harris et al., 1999; Jelali, 2006). Overall, a significant amount of research effort has gone into the development of methods, partly using data from industrial problems of poorly performing loops and partly by using simulated data from continuous stirred tank reactor or the Tennessee Eastman Process which allows the simulation of a complete chemical process (Downs and Vogel, 1993).

1.2 Big Data and Data Analytics

In the process industry, capturing, storing and maintaining data is primarily associated with cost. The market research organisation Gartner has coined the term 'dark data'[1] when discussing operational technology (OT) in comparison to information technology (IT). Dark data is defined as 'the information asset organizations collect, process and store during regular business activities, but generally fail to use for other purposes'. Process data in particular has many potential applications but is inherently underused.

Data analytics retrieve information and turn data into value. Loop performance monitoring is one of very few areas where process data is analysed and turned into information that improves productivity and process efficiency. The results of LPM give an indication about the state of the process control system. The key is that no extra sensors need to be installed and no extra cost in terms of data capture occurs. Instead, the existing dark data is turned into value.

In the age of Industrie 4.0 and big data it is important to ascertain the data ownership. Increasingly, data is seen as an asset rather than a liability. In the automotive industry, car manufacturer compete with the car owner, insurance companies and app developers for the data generated when driving the car, in particular for the geospatial positioning. In the process industry at present, the data belongs to the production company where the data originates. The importance of data ownership, privacy and security increases dramatically.

2 INDUSTRIAL CONTROL LOOP PERFORMANCE MONITORING

ABB has been active in the area of loop performance monitoring for at least two decades. The efforts that were previously distributed across the ABB organization worldwide were consolidated in an effort to take the best out of all solutions and combine it into one offering that can be easily installed by process control experts and non-experts. In 2013, the ABB product ServicePort was launched. Within the first 6 months 70 installations were sold.

Here, we will explain the concept of the solution and highlight the novelties. In total, six patents were granted to protect the intellectual property (Starr, 2003; Tran et al., 2007, Trans and Mast, 2009; Starr et al., 2013, Murphy et al., 2014; Mast and Starr, 2014.). Further nine patents are pending.

In recent years, the notion that LPM is a software product has given way to the concept of supplying LPM as a service (Bauer et al., 2016). The difference is that service has a large consulting aspect providing advice on risk assessment and priority settings. It requires a change in mind-set.

Fig. 1: ABB Senior Service Engineer uses ServicePort's built-in retractable user interface to analyse Key Performance Indicators (KPI) on customer equipment and processes.

[1] http://www.gartner.com/it-glossary/dark-data

Table 1. Delivery schedule of Loop Performance Fingerprint.

Day 1	Day 2	Day 3	Day 4-5
Project introduction meeting	• Set up data collection software • Begin collecting security data • Interview key plant personnel • Check data and make configurations accordingly	• Complete process data collections • Data analysis begins • Exit meeting	• Prepare summary of findings and finalize report • Present findings

LPM is often treated as a software solution only. ServicePort contains a hardware component that is located on site for proximity to the process and security reasons, see Fig.1. The service engineer can access the data on site via a retractable user interface. In a first step, ServicePort collects data from the process control system. Once configured, the data gathering occurs automatic and secure. In a second step the data is analysed on an ongoing basis and stored on the same hardware. The data as well as analytic results can be accessed both on site and remotely by either plant personnel or ABB technical support. A remote access platform (RAP) provides a detailed audit trail of anyone connecting to ServicePort by logging each remote session.

Once the data has been captured, advanced service 'channels' address equipment, process and industry issues. Here, 'channel' refers to a different aspect of data analytics. The most popular channels are control loop performance monitoring and control loop tuning. Other channels include data analytics for cyber security, low voltage drives and the automation system. Data analytics for the automation system identifies software, hardware, system and network performance irregularities. For example, there may be a module bus failure limiting the communication of the control system.

In the remainder of this paper we will focus on the functionality of the LPM. However, similar procedures are applied to other channels. Also, the number of channels continues to grow as more data analytic functionalities are added to the offering. In the following, we discuss the procedure, views and workflow of ServicePort for LPM. We then highlight what has been taken over from previous ABB research effort and what is new within ABB and in the LPM community.

2.1 Loop Performance 'Fingerprints'

An initial analysis referred to as 'fingerprint' is proposed as an entry analysis for process plants which have previously not assessed their control loop performance. The loop performance fingerprint is used to benchmark current control loop performance, identify issues that reduce control performance and outline and recommend an improvement plan. Control loop data analysis is delivered as a consulting service by trained ABB engineers and identifies troublesome loops through data collection, model identification, feedback tuning, feed-forward tuning and controller simulation. A typical schedule for a fingerprint consulting service is shown in Tab. 1. The first day is used to introduce the concept and methodology of LPM to the plant personnel. During Day 2 the data collection is prepared and key plant staff such as operators, process engineers and automation experts are interviewed. During the third day the data collection is completed and the data analysis is conducted. In the following two days a report is generated and the findings are presented and discussed with the plant personnel.

2.2 Loop performance workflow

After the initial fingerprint assessment the performance should be maintained to ensure that the results are consistent and do not degrade over time. This implementation includes regular reports and updates that are aligned with plant personnel meetings. ServicePort provides three different support methods for the continuous monitoring of the control loop performance.

View – The view option allows the engineer to view the raw data used for data analysis. The data can be selected by equipment or process. Raw data is informative to the experienced user who can judge from the nature of the data which root causes are likely. The expert user can conduct this analysis probably more reliably than any algorithm. Key is that the routines need to be automated since the expert user does not have time to inspect each variable individually.

Scan – Data analysis results are presented in the scan view. All analysis results are expressed as key performance indicators (KPIs). The summary of these KPIs is ranked by severity so that the user can begin addressing issues in order of priority. All methods are configured automatically and the user is not required to set any parameters.

Track – KPIs can be managed so that rules defined for each KPI determine when an alert should be sent out. The user sets his or her own thresholds for the KPIs but default thresholds are suggested. If the threshold is exceeded, alerts are sent out by email or SMS.

2.3 Loop performance assessment results

Presently, there are about 600,000 PID loops assessed daily with ServicePort. ABB conducted an analysis of control systems used by customers in multiple industries that revealed the following finding, see Fig. 2. In the investigated plants over the 600,000 loops, the control performance distribution is 30% manual operation, 30% increasing variation, 25% improving production and 15% output out of actuation range. This means that up to 75% of a typical plant's automation investment is not providing benefits. Instead of solving process problems, the systems are not

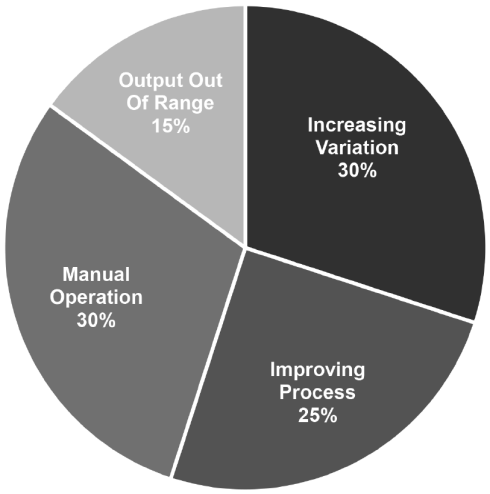

Figure 2. Loop performance assessment results of data analysed by ABB's ServicePort.

operating as they were designed, due to the lack of comprehensive tuning. This indicates that many control system owners are under-utilizing their automation investments.

3 NOVEL LOOP PERFORMANCE CONCEPTS

Loop performance monitoring is, after more than two decades, an established discipline. Before looking into what is new in ABB's ServicePort implementation we define the aspects that are not new.

Loop performance monitoring methods: As detailed in the literature review in Sec. 1.1, there are several established indices to assess the performance of a controller and detect unwanted disturbances such as oscillations and nonlinearity in the time trend. Methods as reported in the literature (see for example the review by Jelali, 2013) are implemented. These range from simple algorithms such as detecting whether a loop is in manual to more complex computations detecting intermittent process disturbances.

Rating of control loop performance quality: The performance of control loop is not a binary value of good or bad but instead it is a grey area. For the ease of interpretation the loops are usually grouped into categories such as good, fair, poor and excellent. Paulonis and Cox (2003), for example, define a 'fair' performing control loop in detail: "Loops in this category are not performing up to potential and should be improved. Control is probably being maintained in a broad sense, but deviation setpoint is likely to be degrading process performance. These loops should be investigated further. Often, the problem is not difficult to find and improvement can be obtained without significant effort. Occasionally, level loops with a flow smoothing objective which are performing adequately end up in this category. (Score range 20-40)."

There are several novel aspects to ABB's ServicePort which are subject of several patents. Two of these aspects are explained in the following section and are embedded in the workflow as described in Sec. 2.2.

3.1 Loop performance monitoring as KPIs

Initial implementations of LPM calculated loop indices and presented them to the LPM software user. This was found to be a major hindrance to the roll-out of the solution because the user where not always trained to interpret the results correctly. Even if a performance index was scaled to be between 0% and 100% the user was uncertain whether 60% was a sufficiently good result or whether the loop required attention.

A shift in mind-set occurred when it became clear that loop performance indices should be expressed in terms of the process and not in terms of control. All reported LPM results should have a diagnostic capability so that personnel who are not LPM experts can understand the result. A first step is that the indices are grouped into three categories according to the underlying problem: Control, process and signal processing, see Fig. 3. Arguably, the most important category relates to the process since the issues flagged in this category can trigger a maintenance action.

A loop performance monitoring result should be expressed as a key performance indicator (KPIs). KPIs are understandable, measurable, and can be monitored against a target. They are assessed periodically and measures to improve the KPIs are suggested. It is important to note that indices tend to be practical loop performance indices. An example of a KPI is the number of loops in manual, the final control element out or range or compression of the measured variable.

Fig. 4 shows a screenshot of the KPI dashboard in ABB's ServicePort. The top graph shows an accumulated view of all KPIs in the three categories – control, process and signal processing – over the past five days from Thursday the 9th to Monday the 12th. The data range can be selected in the dialog box below. The three categories are further detailed in the three plots underneath in Fig. 4. This shows that the most common causes in each category are loops in manual (17%), final control element (FCE) out of range (36%), and step out or quantisation (17%) respectively. Clicking on each bar provides a drill down analysis and will show the individual loops with the issues.

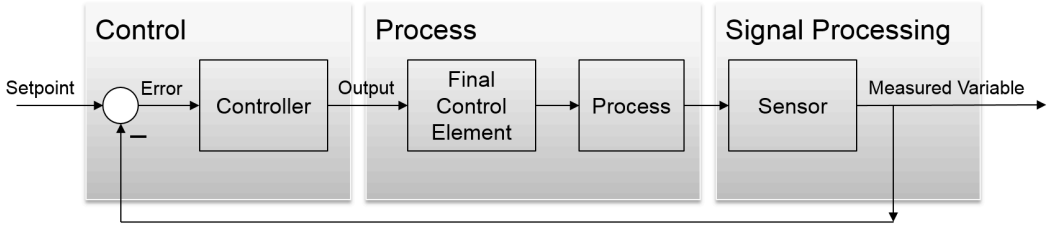

Figure 3. Categories of LPM reported problems by origin in the feedback loop.

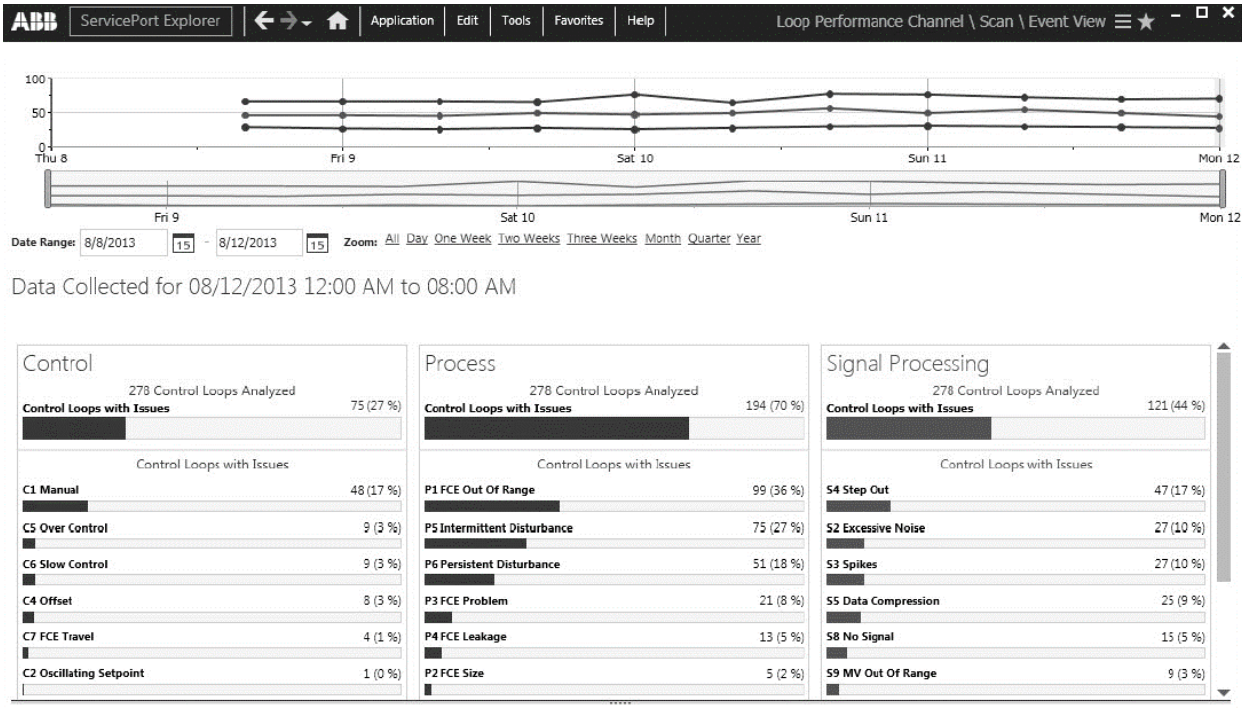

Figure 4. Screenshot of ABB's ServicePort loop performance monitoring channel.

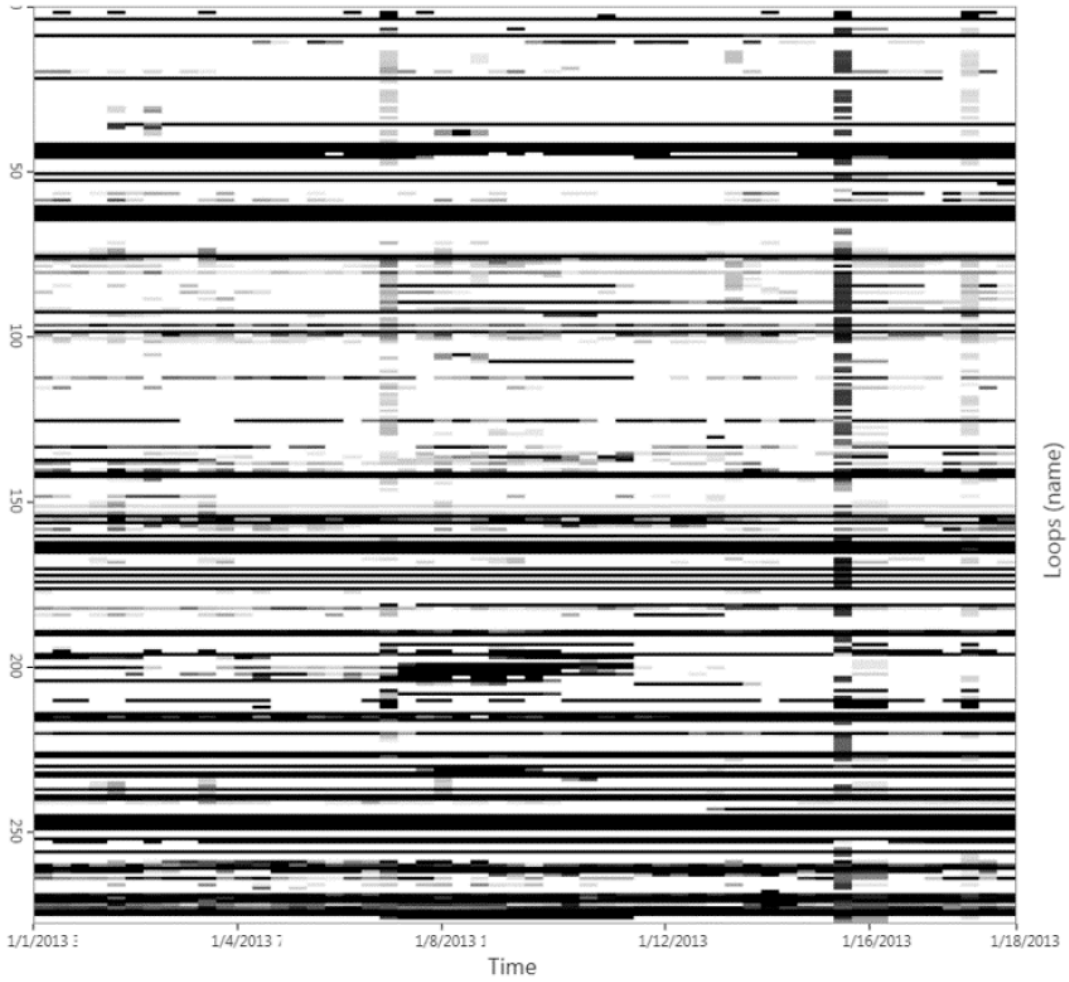

Figure 5. Contour map plotting final control element out of range problem over time.

3.2 Contour map

Identifying control loop problems is equally important as tracking the progress of an error. In this new analysis report, KPIs are therefore plotted over time in a contour map. An example of such a contour map is shown in Fig. 5. The x-axis is the time axis divided into eight hour intervals or operator shifts. The On the y-axis are all control loops in the plant listed and represented by a horizontal bar. There are roughly 270 in the example. The shading of the bar indicates whether there is a fault present in the loop – dark areas indicate that the severity is high while white areas indicate that not fault is present.

The contour map not only allows to view the development of faults in each loop but also the identification of clusters of loops. Also, there are periods of plant upset where all control loops show problems. These manifest themselves as vertical lines that pervade most of the process. The visual inspection of the contour plot gives an immediate picture of the plant health over time. Further developments will look into automatic detection of clusters.

4 RESEARCH DIRECTIONS

In our view, there are two main areas that warrant the investment of more research effort. The first relates to the indices on their own and the second to the various aspects of plant performance of which loop performance assessment is only one.

First, many indices to monitor the performance of control loops have been developed. When implementing these indices in an industrial solution these indices have to fulfil certain criteria:

- Suitable as KPIs: Performance indices have to be meaningful so that a non-expert LPM user can interpret them. Indices should reflect the performance of the process rather than of the control strategy.
- Reliability: Indices should give a 100% reliable result that does not warrant discussion. Particularly damaging to the credibility are false alarms. In general, a loop performance index should rather have false negatives than false positives.
- There should be no 'tuning' required to the index, that is, no parameterization. Parameters need to be proposed by guidelines. In reality, if there are parameters to set, the index will not be used.
- Standard categories (good, fair, poor) should enable the comparison of different indices, for example see NE 152 published by NAMUR (2014).
- An un-biased comparison of indices assessing the same issues using standardised sets of industrial data would be helpful.
- To our knowledge there is no reported index measuring quanitization of the measured variable which is due to senor inaccuracies.

The second area of future research concerns the integration of different aspects relating to plant performance, in particular the following

- Integration between loop performance monitoring and loop tuning. Often, the two areas are implemented unrelatedly but synergies can be achieved if the two concepts are combined.
- Automated procedure for plant-wide disturbance analysis. There have been several attempts to track the root cause that has travelled along the product stream or utilities in a process. However, root cause analysis is still a manual task in comparison to LPM analysis.
- Inter-connection between different aspects of plant performance monitoring, or 'inter channel causality'. An advantage of software solutions such as ABB's ServicePort is that information from different solutions is stored in one location. We often think in silos when it comes to asset health. However a drive can impact a control can impact an alarm limit. A full hard drive can stall a controller, and result in failed KPIs. Being able to apply cause and effect to channel KPIs would be very helpful with regards to troubleshooting.

5 CONCLUSIONS

This paper looked at loop performance monitoring from an industrial implementation and solution viewpoint. Today, loop performance monitoring is seen more holistically and combined with the monitoring of physical equipment or assets. The terminology 'loop health' and 'asset health' is used to express the tight coupling between control loop monitoring and plant maintenance.

When identifying high and low priorities of maintenance it is useful to draw on the topics 'circle of concern' and 'circle of influence' to gain ownership of actions (Covey, 2000). The circle of concern is comprises a wider range of concerns a plant manager has – from managing people to ensuring safety, quality and maximum profit. The circle of influence, on the other hand, comprises only the concerns that can be acted on. For example, a plant manager can decide to produce more of a certain product but will not be able to change the price of crude oil. Focusing on the circle of influence allows prioritizing the issues in the plant that are of concern but also in the region of influence. Thus, the circle of influence can be expanded and the plant performance can be improved holistically.

As automation equipment grows, the need for a person to utilize technology to cast a larger net is also needed. In the past the manual efforts of physical inspection was the norm for performing asset health evaluations. Today, the expansion of automation makes the traditional efforts much less effective. Today, rather than evaluate one loop at a time, we need the ability to evaluate one hundred loops in the time it took to do one. This cannot be done with training or manual tools. Technology has to help us with that. This is why ABB has invested in ServicePort. It provides a platform for automation users to be more efficient, identify incidents

in record time, and provide the building blocks to establish predictive notification. In so doing, a user can move from a reactive service where waiting for operations to identify a failure occurs to a proactive solution where operations never see an automation failure.

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