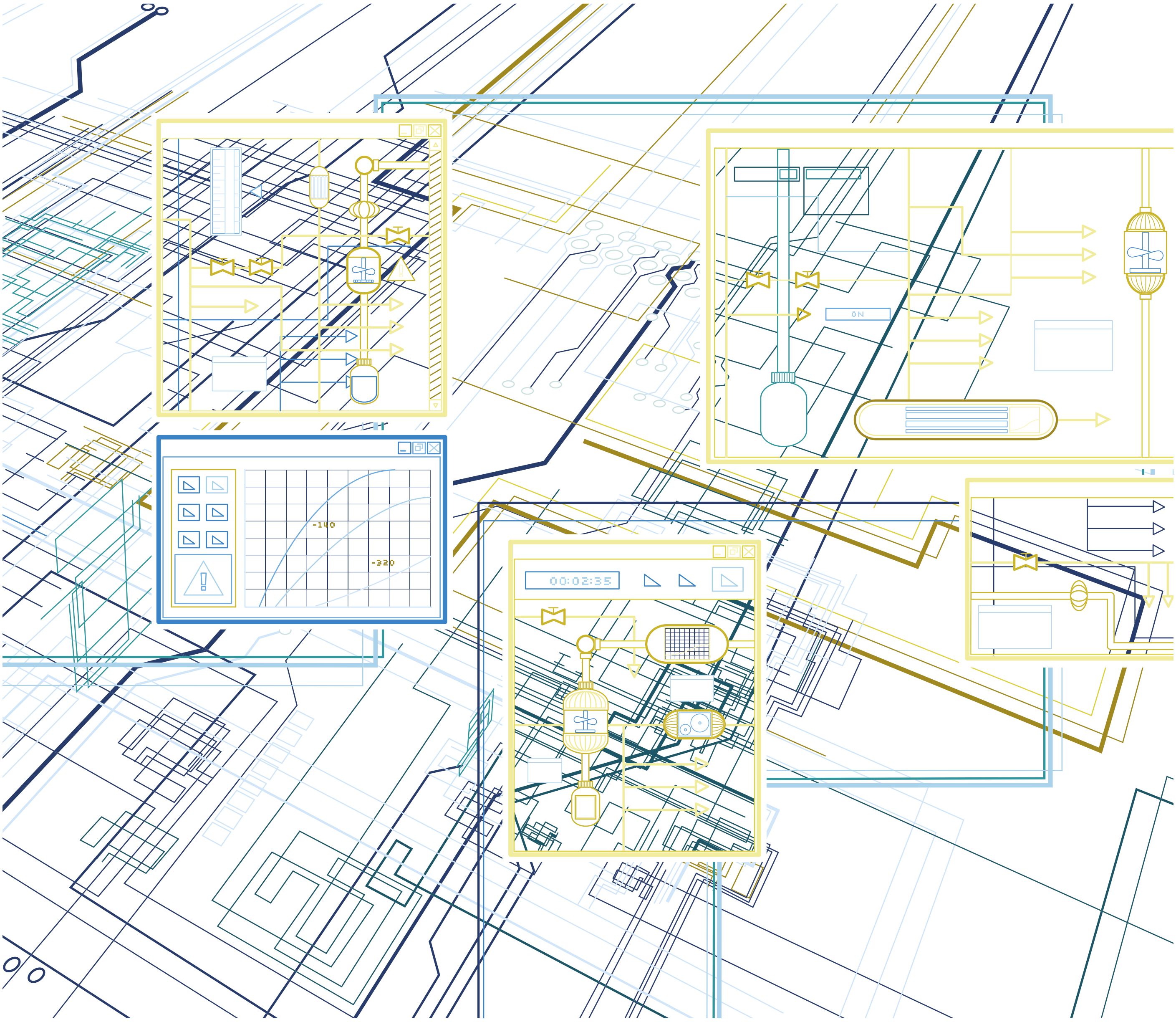

Wise warnings

Providing useful business insight by turning process data into early problem detection warnings

GEOFF ARTLEY – The refining industry today is under extreme financial pressure. Margins are being whittled away, the use of high sulphur, high metals heavy oil is becoming the norm as clean light oil prices increase. The industry is losing knowledge through retirees. However there are solutions to help tackle these challenges. Refining processes can be operated at their operational optimum at a relatively low capital cost, using the experience that is tied up in the process history within the automation system.

Modern distributed control systems (DCS) can store vast amounts of historical data which in turn contains vast amounts of information about the process. Using that data and converting it to information enables the process to be operated closer to the optimum. The key thing to remember here is that this can be achieved with a relatively low capital outlay.

Modern DCSs generate terabytes of data which are often just stored in the control system historian for regulatory and compliance reasons. This data remains unanalyzed and is discarded once the regulatory storage date has passed. Yet within this data there is a goldmine of information that, if interpreted correctly, can be transformed into information and knowledge and used to improve the profitability of the enterprise.

The challenge for many processes is maintaining tight control of the process by taking timely corrective action. Early recognition that the process is moving away from the normal operational envelope reduces process variability and allows the process to be operated closer to its optimal limits. A data mining application enables early recognition by determining when the process is moving away from "normal". This is achieved by using the historical data to benchmark the process for "normal operation", comparing the current operation to the data-mined normal, and then detecting when the operation is moving away from the required normal.

Process alarms are currently used for two purposes: protecting the equipment and the process from damage and protecting the process from straying outside normal operation. Process alarms that are used to protect equipment and the process are often invoked too late for the operator to take controlled corrective action, except to shutdown or take other extreme evasive action. By using an online data mining application, abnormal operation can be detected before such a process alarm is activated.

These applications exist and are in use in some industries today. ABB is able to offer Early Detection of Abnormal Operation (EDAO)[1] based on AJMC's MS2 online application [1] and is also developing another early fault detection (EFD) application [2] in partnership with Shell/Statoil. The EFD solution is a sophisticated asset monitoring application that builds on knowledge of multivariate changes. Rather than considering a single variable, multivariate means that variables are correlated and this correlation should be taken into account when considering the response of the measurement of interest. Most processes are multivariate in nature. The applications use principal component analysis (PCA) to capture the variability within the data, related to multivariate changes.

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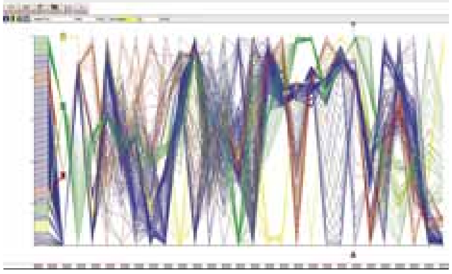
The basic principle is that data that is representative of normal operation is used as the operating benchmark and this data is used to create the benchmark model. Current process variable values are compared to this benchmark model to determine whether the current data is within or outside of this normal operation.

1 Parallel coordination visualization (PCV) plot

This technique provides a view of relationships between many diverse process variables, for instance quality parameters such as pH and viscosity, process parameters such as maximum pressure or temperature and calculated values such as operation duration or shift identity. Results of further analysis, such as principal components, can be viewed on the same plot as primary variables.



To assess whether the data is within or outside of the benchmark model, a measurement is required. In the case of MS2, this is the square of the errors between the current data and the benchmark model data. If this value goes high this would indicate that the current operation is very different to the benchmark model and is abnormal.

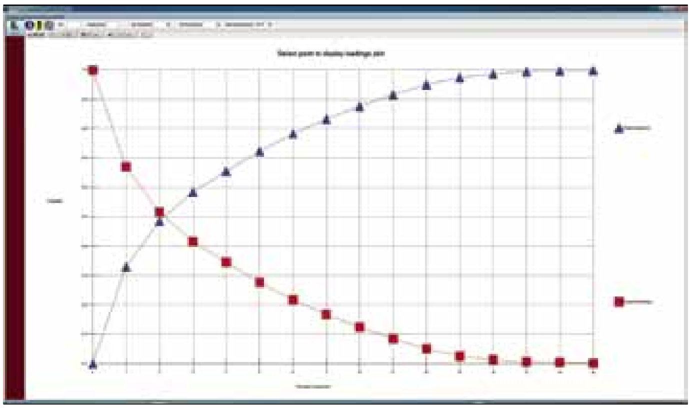
When the application recognizes changes that are outside the normal variability of the process it advises the operator that a potential issue is occurring. These change issues can be detected before a process alarm has been invoked, giving the operator time to take corrective action. For large rotating machinery, similar applications have provided early warnings days, or even weeks, in advance of a machine failure allowing planning time to correct the fault before a catastrophic failure.

To apply the solution universally, the application needs to be DCS independent. Hence data should be transferred using

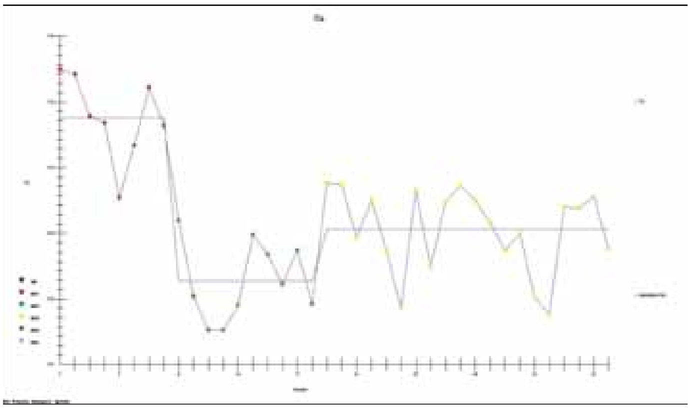
Footnote

1 ABB's EDAO system incorporates the MS2 process diagnostics system, developed by AJM Consulting with assistance from the Centre for Process Analytics and Control Technology at Newcastle University. MS2 has been successfully applied to a range of process sectors including petrochemical, chemical, pharmaceuticals, nuclear and advanced materials.

2 Example of a scree plot



3 Manhattan plot showing temperature



OPC, which is a standard which specifies the communication standard for real-time plant data between control devices from different manufacturers, and offline data imported using csv and xls data files.

Process operators and engineers often prefer to look at graphical views of the operation and, in the case of MS2 and EDAO, this can be provided in scores plots. Scores plots are the principal components plotted against each other (three principal components produces three graphs, four principle components produces six graphs, and so on) and they are able to depict the "normal" or "required" representation of the benchmark data in ellipses of confidence limits that include all of the data. The current data is plotted alongside this benchmark data and if the current data is within the confidence limit ellipse then the representation of the operation is classified as "normal and required". Once the data point moves outside the confidence limit ellipse it is classified as "abnormal". If it is later decided that this data is not abnormal then it can be included in the model for normal data to improve the model and to eliminate false alarms arising. The ability to re-classify outlying data is an important concept in preventing false alarms.

If a particular abnormal situation has been seen previously and analyzed to determine a cause and corrective action, for ABB's system 800xA, a text string message can be sent to the operator screen providing advice as to what action can be taken to remedy the situation. This builds operator confidence in using the application; otherwise the apparent black-box nature of the application may discourage operator use. The mathematics within the application is relatively complicated and determining an ultimate reason for an abnormal situation would involve somewhat complex analysis to decide on an action to be taken. Any new analysis in this respect would normally be undertaken by an engineer or expert.

Applying EDAO

There are four simple steps for deploying EDAO applications online. ABB personnel are able to support clients in all of these steps:

1 Decide on the measurement of interest.
2 Create the benchmark model.
3 Set up the communication link.
4 Configure the interface.

The first task is to decide on the measurement of interest. This is the most important step and it is vital that this variable represents an overall target for the process, particular process area, or item of equipment. The measurement of interest would normally be a high level measurement such as an intermediate or final quality or throughput or impurity. It may be necessary to create a derived tag to act as the measurement of interest, for example, in the case of rotating equipment it may be an efficiency or throughput measurement.

The user then analyzes which measured variables relate to or affect the chosen measurement of interest, and could highlight abnormal operation. Any data used for this analysis needs to be screened and either corrected or discarded due to bad values, high data compression, zeros, and so on. At this stage, any reasons for the abnormal operation are also determined with the intention of passing this information to the operator for situations that have been seen before.

The second step is to create the "normal required" benchmark model of the process for both the measurement of interest and the variables affecting the measurement of interest. Determining the contributing variables for periods of operation where the measurement of interest is within the required range or normal is done offline and uses historical data.

For viewing the data a parallel coordinates (PCV) plot is very useful and will determine any univariate reasons for abnormal operation → 1. A PCV plot shows all of the data, with each variable along the Y-axis joined to the equivalent (normally on a sample time basis) value of another variable along the x-axis. A PCV plot is one of the main viewing

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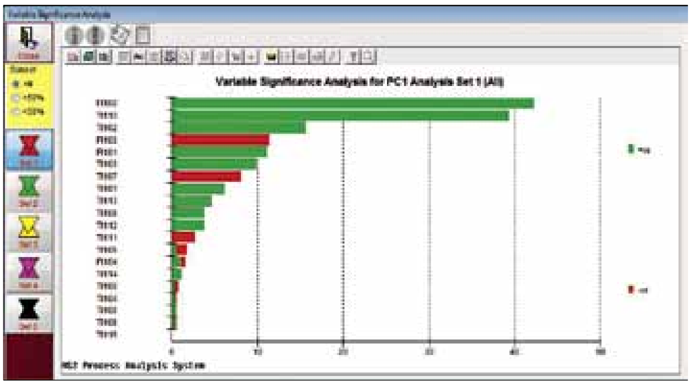
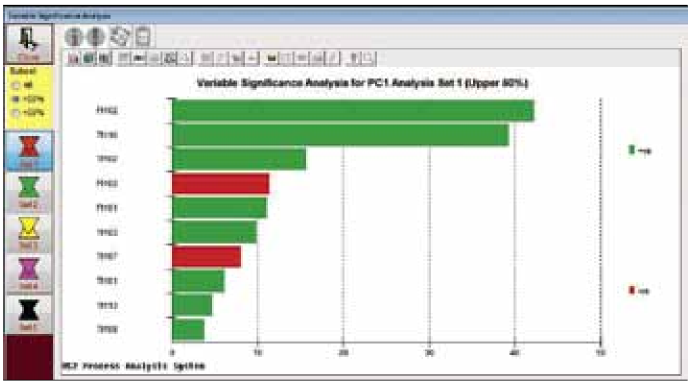
4 Variable significance analysis showing which variables contribute to the cluster set



5 Example of a variable significance analysis



Early fault detection applications are set to become the expected way of informing the operators that the important process variables are trending away from good control.

tools used by the MS2 and EDAO application.

A PCV plot is univariate but is a useful tool for seeing all of the data. It is unlikely that univariate analysis will completely determine the reason for abnormal operation; also any univariate reason is likely to have been found through other data viewing and analysis methods, such as, time domain plots of the variables. For multivariate analysis, which is the likely required analysis, principal component analysis (PCA) is used to find the variables contributing to abnormal operation.

The user or expert needs to choose the number of principal components (PCs) that represent the variability of the process and the contributions to the measurement of interest. This is also carried out offline. Choosing the number of PCs is a significant factor in obtaining good data analysis. The analysis can be affected by choosing too many PCs, which could slow down the analysis, as well as too few PCs, which could mean missing vital information. There are several means of choosing the optimum number of PCs, for example, perhaps only those PCs with eigenvalues that are greater than one are relevant. This is based on the Kaiser-Guttman rule for significant PCs. Often this provides a sufficiently representative model of the variability.

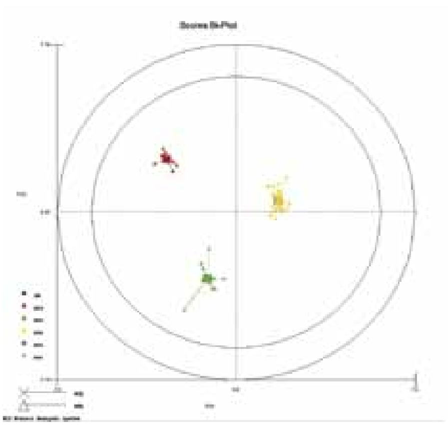
Between 75 to 90 percent of the variability should be represented by the number of PCs chosen. If the automatic choice method does not provide a good solution analysis for the measurement of interest then the number of PCs can be chosen manually to represent more of the variability. A scree plot shows graphically and numerically how much of the variability is represented by the number of PCs chosen → 2.

As part of the offline analysis other graphical views could be used to finalize the reasons for abnormal operation; such as; Manhattan trends → 3, CUSUM trends → 3, variable significance plots → 4 and → 5, scores plots → 6 and → 7 and so on. The Manhattan plot shows the time series variable value (in blue) the CUSUM plot (in green) and the Manhattan plot (in black) showing the points of significant change. The sensitivity of the Manhattan analysis can be chosen, to assess the significant change points and compare them to the measurement of interest change points. The Manhattan analysis is a powerful tool in assessing the areas of significant change and determining the contributing variables. This plot is only available as part of the MS2 and EDAO tools.

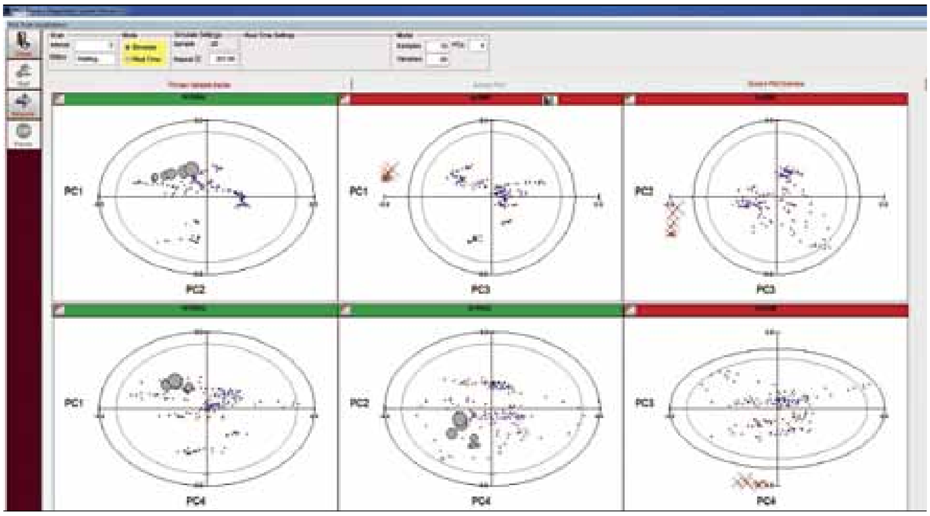
For online analysis the current process values that have been determined to contribute to the measurement of interest are compared to the benchmarked model to determine whether the current values of the variables are within this benchmark model range.

The next step is to set up the communications link to allow current on line data to be used by the application for analysis. Real-time data would be generally passed over to the application at some specified frequent interval using OPC. The user needs to allow time for the application to run its algorithms on the current dataset then, where the application detects operation outside the benchmarked operation, an alert can be sent to the operator workstation screen as a warning that the process is heading off in an undesired direction. Operation that is

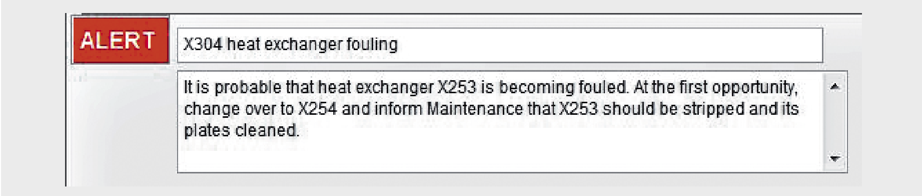
6 Scores plot showing how different analysis sets form clusters



7 PCA score plot providing a fault signature



8 Operators diagnostic message



subsequently assessed as being desirable is easily incorporated into the benchmark model to prevent future unnecessary notifications.

Once the communications link is established the user needs to consider how the operator will be alerted. ABB is conscious that creating an alarm is relatively easy therefore it's possible to have too many operator alarm alerts. However, abnormal operation alerts could be created in many ways for example; via mobile telephone SMS messaging to the engineer responsible for the process area, or to the responsible engineer's computer or by a text message on the operator workstation. When the process

Operation that is subsequently assessed as being desirable is easily incorporated into the benchmark model to prevent future unnecessary notifications.

operation moves outside the benchmark range, operator alerts can be created (either through an alarm or simple graphical color change on the operator workstation, and so on) to inform the operator that the measurement of interest is moving away from its desirable value. This detection would be observed before any process alarm is invoked therefore leading to early detection of an abnormal situation. This could be achieved, for example, by displaying the square of the differences (for MS2) as a bar graph with limits that invoke a color change when the value goes high. The operator is then able to investigate the various graphics for confirmation. Also, as previously mentioned, if the excursion pattern has been seen before and analyzed and a reason found and configured on the DCS (for example, a fouling heat exchanger or a blocking filter) then a text string message can be displayed on the HMI to suggest actions that the operator can take to alleviate the issue → 8.

Outcomes

These early fault detection applications are set to become the expected way of informing the operators that the important process variables are trending away from good control. The current process alarms are then able to be used for real emergency situations only rather than the current practice of trying to cover poor operation as well as protection. These applications involve complex mathematics but are normally black-box applications as far as the operator is concerned and do require engineer or expert intervention for full understanding.

When assessing the benefits, the cost of investing in such an application is offset against the massive cost of loss of production or critical equipment replacement.

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References
[1] Offline MS2 is marketed through AJMC, http://www.ajm.co.uk. Online MS2, called EDAO, is currently marketed through ABB UK at St Neots
[2] ProcessInsights – refer to Knut Hovda or Hans Petter Bieker ABB Norway