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DEVELOPING AN INTEGRATED CONDITION MONITORING SYSTEM

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Abstract: This paper discusses some of the background of condition monitoring systems, the need for integration between the technologies, and some of the approaches already taken in the industry. This paper also discusses some of the issues faced when designing an integrated condition monitoring system. The issues include: database structure, similarities between test types, the difference between data and information, access to data and information, and where to draw the line between condition monitoring and maintenance management systems.

Key Words: Condition monitoring; data collectors; integration; oil analysis; performance analysis; thermography; vibration analysis; wear particle analysis;

BACKGROUND: For many years it has been broadly recognized that condition monitoring (predictive maintenance) can reduce maintenance costs. By monitoring the vibration, lubricant, wear particles, performance parameters, electrical parameters, and many other indicators, it is possible to determine the state of a piece of equipment. The different technologies are used to test for different conditions, and are appropriate to different kinds of equipment. In many cases there is overlap between the technologies, for example vibration and wear particle analysis can be successfully applied to rotating machinery. It is also true that some technologies can reveal different information about the same equipment, for example electrical analysis can tell you about eccentricity and broken rotor bars whereas wear particle analysis can only tell you about the components in the path of the lubricant.

In many industries, multiple technologies are implemented, often by a combination of in-house and external services. However in almost all cases, the results of the various tests are reviewed by different people, often in different departments, using different software packages. Rarely can one user look at the wear particle analysis results and the vibration results related to the same equipment at the same time, even though together they paint the clearest picture of the condition. Instead, two people are forced to make individual assessments and hope to meet and discuss their results. As a result there has long been a desire to create one system capable of tracking all of these data types, with the appropriate analysis and reporting tools.

There are other challenges and problems that can arise due to this separation of technologies:

- Pockets of expertise form. It is rare to find someone expert in more than one field. Thus the organization is exposed to that person leaving.
- Poor decisions can be made due to that lack of information.
- Problems can be missed altogether. Individually the vibration, oil, etc. data may not clearly show that a problem exists. However when combined, a clear picture of an incipient problem may be revealed.
- It is difficult to perform root cause analysis. Only with the history of all the data is it possible to see what may have lead to a problem. Rather than simply fixing the problem, it is always best to understand and resolve the cause of the problem.
- Ownership of data and results can occur, resulting in inefficient and non-effective communications between parties.

A DESIRE FOR THE FUTURE: The ultimate solution to this problem, in the author's opinion, is as follows:

- The system should have one database which holds all of the key equipment and test data, and all of the recommendations and reports.
- The system should deal equally well with all major technologies, and should be able to grow to accept others.
- The system should be centered on the equipment rather than the test data, after all it is the equipment we are maintaining.
- The system should allow three basic levels of access to data and information: the technician who performs the test and performs basic analysis, specialists and systems engineers who are required to solve the problem and make a recommendation, and upper management (maintenance managers, plant managers, etc.) who need fast access to the recommendations without being confronted by raw data.
- The data and information should be available at any workstation, and should be integrated with other data management systems, for example maintenance management (CMMS) and distributed control systems (DCS).
- The system should support condition monitoring products from a variety of vendors, rather than limiting the user's choice.

- The final recommendation should be derived from all the information available, as shown in Figure 1.

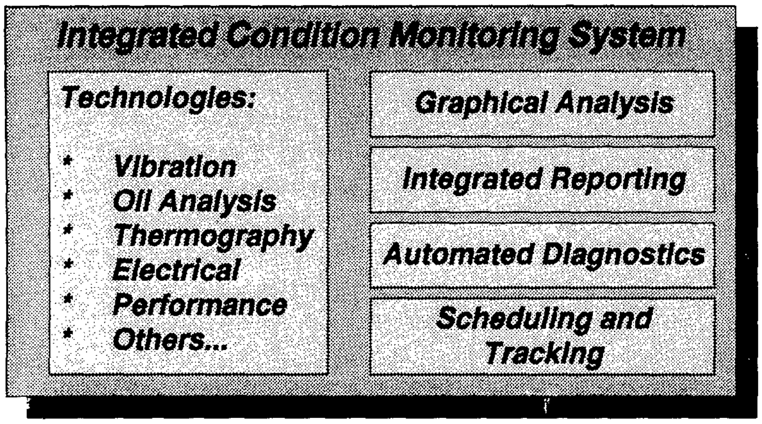

Figure 1: Structure of integrated condition monitoring system

As with any software package, additional requirements include:

- Ease of use and quick access to commonly used functions, as these systems have to be used by people unfamiliar with computers and software.

- Open database structure, for example SQL, to allow the user ease of movement of data in and out of the system, and for flexible reporting using external reporting tools.

- Support for client-server networking to reduce computer requirements and improve network performance.

- Use of off-the-shelf tools, and support for the integration of other tools via DDE and OLE, where ever possible to allow for non-vendor-specific growth.

- Flexible report writing to enable a clear and professional presentation of results, and to reveal hidden facts in the data (for example, do we have a bad pump manufacturer?).

- Support for financial analysis, first to justify the continued growth (or existence as the case may be) of the condition monitoring program, and second to justify individual recommendations.

WHY MULTIPLE TECHNOLOGIES? It has long been known that no one technology can give all the answers. And even though each specialist will have his or her own favorite technology, only a combination of information will lead to an accurate diagnosis. Your confidence level will grow considerably when a fault is supported by more than one source of information. And technologies have their sphere of influence: vibration cannot tell you about contamination occurring in the lubricant, and oil analysis cannot diagnose imbalance problems.

Remember, when performing a diagnosis we are attempting to learn four things: what is the nature of the fault, what is the severity of the fault, how soon must a repair be performed, and what is the root cause of the fault. When making a final recommendation for a piece of equipment, we need to know about the machine as a whole - not just the bearings or the gearbox. Only a combination of technologies can reveal this combination of information.

As a simple example, vibration readings may indicate a moderate bearing problem on a pump. Wear particle analysis may reveal particles of lead and tin also supporting, and adding confidence to the bearing call. Just knowing this you may recommend that the machine be left in service with increased monitoring. However if you were also collecting performance information on the pump, and saw that the efficiency was down, you may choose to overhaul the pump earlier, replacing the bearings and resolving the efficiency problem, as a reduction in efficiency could affect the process at large, and increase the energy costs.

WHY SHOULD THE SYSTEM BE INTEGRATED? With information held in separate systems, a user must be familiar with the operation and nomenclature used in each system - and naturally must have access to those systems - before an integrated conclusion can be made. Otherwise there will have to be frequent meetings where all of the specialists will come together to discuss their individual findings and arrive at a consensus. This can often mean going back to their respective systems to perform additional analysis.

If all of the information is held (or available from) one system, all users will be able to make these kinds of decisions in a much more timely fashion. It assumes of course, that these users are familiar with all technologies. However, the ultimate situation is one where all users have a level of competency in each technology. In any case, individual experts (or computerized expert systems) should first verify and process the data, turning the raw numbers into easily understood information, before it is used in a decision making process.

Other benefits to using an integrated system include:

- The level of cross-competency will grow with time as users inevitably become exposed to the different technologies.

- The system should be easier to learn, use and maintain given that just one software package would be used.

- All reports and analysis methods would be more consistent, reducing the chance of miss-communication.

- All users would know one place to turn for the key information.

ALTERNATIVE APPROACHES: There are a number of ways an integrated system could be developed. Each have their strengths and weaknesses.

Combination of separate systems: One approach, as depicted in Figure 2, is to create a number of independent condition monitoring systems: vibration, oil, thermal imaging, expert system, etc. with a simple menu system to jump between them. A user of such a system would be required to make a conscious decision which technology was necessary for a given task and select the appropriate package. Ideally there would be a consistent user interface, and there should be some kind of link between the data so that comparing data would be possible.

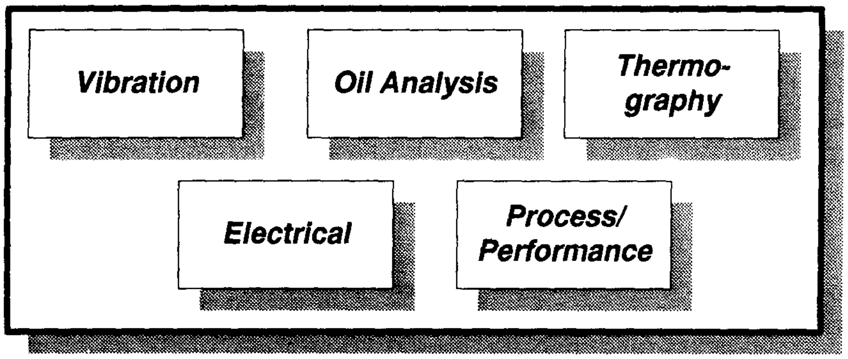

Figure 2: Combined system

The strengths are:

- Users focused in one technology area would have a dedicated package to learn.
- The individual packages are probably less resource intensive than a fully integrated system.
- It would be possible to choose packages from different vendors (although the level of integration may be reduced).

The weaknesses are:

- It is likely that the user interface is not consistent between packages.
- It is likely that there would be more than one database.
- It is therefore likely that equipment would have to be described many times.
- It is likely that there will not be a clear link between tests and equipment in the different packages. The odds are high that users will describe their equipment differently.
- It is likely that most users would not actually utilize more than one technology.
- It is likely that the entire system would be more difficult to learn.
- It is likely, therefore, that the full benefits of integrated condition monitoring would not be realized.

Vibration centered system: Another approach, as depicted in Figure 3, is to take a vibration system and add the required fields and analysis tools to support other technologies like oil analysis, thermography, etc.

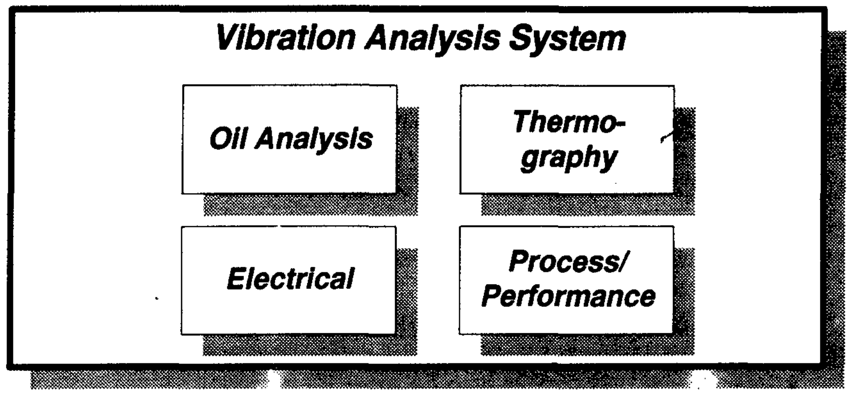

Figure 3: The vibration centered approach

The strengths are:

- If you believe that vibration is the key technology and other technologies simply support vibration, this structure makes it easy to compare data.
- Users familiar with vibration may find it easier to migrate to other technologies.

The weaknesses are:

- Users unfamiliar with vibration will have to become experienced. They will see this as a kludge.
- It is likely that the non-vibration data will be forced to fit the vibration model. For example, unlike vibration, not all oil samples are associated with just one machine. This subject will be discussed in greater depth later in this paper.
- It is unlikely that the system will be terribly flexible. It may be difficult/tedious to describe and access the data.

Separate systems, centralized integration: Another method, as depicted in Figure 4, would have separate condition monitoring systems (potentially from different vendors) for oil, vibration, etc., with a central software system that is able to read data from the other systems on demand. The central system would enable the user to view a variety of data, thus enabling an integrated decision.

The strengths are:

- This system would be independent of any vendor. The user could purchase the strongest packages in the different fields.
- The system could potentially be expanded to take data from other systems, thus extending the range of analysis.

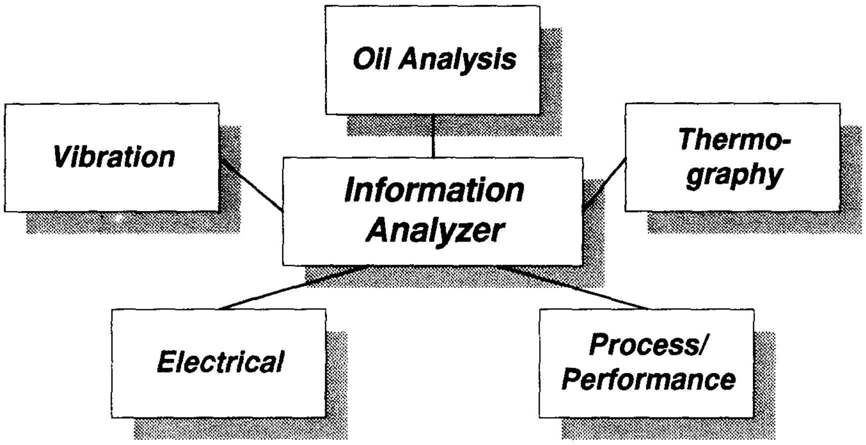

Figure 4: Centralized information analyzer

The weaknesses are:

- Special modules (currently unavailable) would be required to integrate the different packages. They would need to know how to read the stored data.
- Significant integration and customization efforts would be required before the system could be used. Issues such as networking, communications, and access would complicate the set-up.
- It is likely that the individual condition monitoring systems would be used for the detailed analysis, while the central system is used for an overview of the data.

One integrated, extensible system: The final method, the one preferred by the author, is to create one software system, with one database, one user interface, one analysis tool, one reporting tool, and one place to go for summary information about the condition of a piece of equipment. This system is depicted in Figure 5. The system would support a number of different technologies - as many as possible from multiple vendors. And the system would support the flexible creation of 'special test' modules that would support practically any maintenance or performance test performed in the plant.

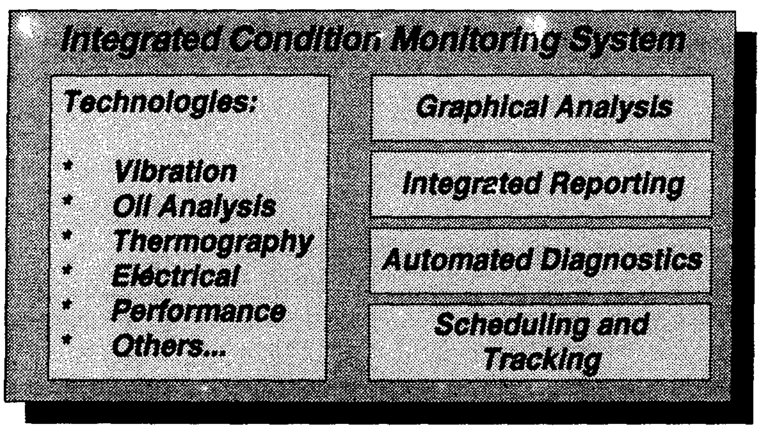

Figure 5: Integrated system approach

The strengths are:

- All users would have one system to turn to for up-to-date information.
- All users would have one software package to learn.
- The system would support growth into different technologies.
- The user would benefit from all the strengths of integrated condition monitoring, as described earlier in this paper.

The weaknesses are:

- Given the level of integration, it is possible that any individual technology would be more involved to use than if it were a single technology package.
- It would be perceived to be more vendor specific than the other alternatives mentioned. If the vendor of this system did not choose to support a particular technology, the user would be unable to utilize it in an integrated sense. Instead the user would be forced to adopt the first method described, where that one technology would be used separately.

CHALLENGES: There are a number of challenges to overcome before this final method can be made to work. These are not only issues that the developer of the system had to overcome, to a large extent they are issues that the user must be aware of as well. The flowing discusses just a few of the challenges.

How Far Should You Go? The first question to ask is how far to take the concept of integrated condition monitoring. For example, one could look at condition monitoring as just vibration, oil, thermography and motor current analysis. But as you delve more deeply, other questions and opportunities arise:

- When you consider oil analysis, most people think of Used Oil Analysis (UOA), where the user is interested in the condition of the lubricant, and Wear Particle Analysis (WPA), where the user is interested in the nature of the particles found in the lubricant. First, should the system support an on-site laboratory, with an interface to the various instruments and batch processing of samples, or just support the access of data from centralized laboratories? Second, should the system stop at UOA and WPA? What about other laboratory tests: transformer oils, fuel oils, soil tests, to name but a few. Why shouldn't the system support other tests types?

- What about process/performance analysis? Many vibration collection systems will allow a user to collect temperatures and pressures from the machine under test, but in general this is restricted to just a few readings, if any, and certainly not enough to tell you about the operating characteristics of the machine. And what about the rest of the process? If the data collected via the Distributed Control System (DCS), and the data collected via the routine 'logs' was available to the system, a much more complete picture of machine and plant condition could be made. Perhaps the system should also support hand held loggers that could be used to collect the logs. The question then arises of what should be done with all that data. First, it is usually more useful to compute some more informative parameters, such as efficiency, from the raw data. And second, rather than having to review the levels and alarm status of all the collected data, a simple expert/advisory system should be used to reduce the mass of data into useful information.

- What about the variety of other tests performed in the plant: megger readings, diesel performance tests, crank web deflection measurements, and others? This information can tell you about equipment condition, so it should be part of an integrated system.

The tests and technologies mentioned above all play an important role in the assessment of equipment and system condition. It is up to the individual user and corporation to decide which tests should be performed, and what to do with the data. But as you can see, the problem is not truly solved by simply combining the 'traditional' condition monitoring technologies.

Database Design And Data Access: One of the keys to a successful system is in making it easy to define all of these tests, while offering all of the flexibility described thus far. When you sit down with experts in each of the individual fields and ask how they would describe their database hierarchy, you will get different answers. For example, the vibration expert will describe a machine with vibration test points, as shown in Figure 6. The oil expert will describe oil sample points that relate to individual components. Thermography users are concerned with items around the plant that have been identified as having a problem: air ducts, switch gear, motor bearings.

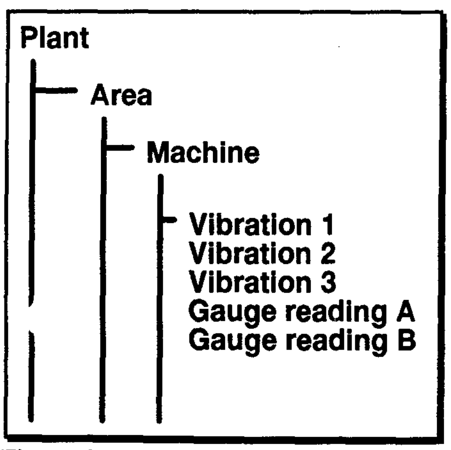

Figure 6: Typical vibration-based view.

If the system is to have one database, it needs to have a consistent hierarchy that supports these different views, while at the same time allowing the user to access the data in the most convenient manner. At the end of the day, the key is to be able to quickly access data related to the equipment under consideration - that is the only way an integrated decision can be made.

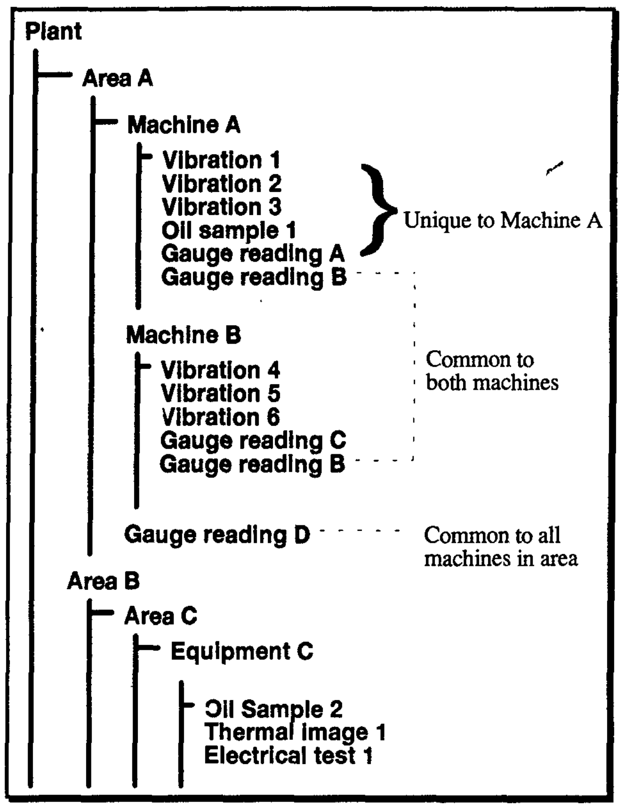

Figure 7: Integrated view of the database.

The second hierarchical diagram in Figure 7 illustrates how the database can be structured to support this variety of test data. It also illustrates a number of points:

- In some cases it is convenient to simply describe one or two levels in the hierarchy. In other cases it is desirable to add additional layers.
- It is necessary to show that some measurements are related to more than one piece of equipment. A measurement such as Vibration 1 is related to just Machine A. Gauge Reading B (a header pressure for example) is related to two machines: A and B. And Gauge Reading D is related to all machines in Area A (an ambient temperature for example).
- Although not illustrated in the diagram, it is also desirable to have more than one way to get to the same item of equipment. In the most simple case, one user may like to access a pump via its physical location (select the plant then the building). Another user, the Systems Engineer for example, may also like to describe equipment according to the system it belongs to. So the Systems Engineer may first select the circulating water system to find the same pump.

Test Synchronization: Another important issue when attempting to compare test results from different technologies is the timing of those tests. Ideally all tests will be taken on the same day, under the same conditions. In reality this does not happen. Even if tests were taken on the same day, test results are not always immediately available. In the worst case, oil samples may be taken before an overhaul and vibration readings after. The user must be sensitive to this issue when performing comparisons.

User Education: A much larger issue is whether individual users will have the expertise to understand the data available in the different technologies. One thing is certain, when a system like this is first installed, it is important that inexperienced users are not looking at totally new data and expected to make decisions. Instead, the people most familiar with the technology should first review the data, ensure that it is valid (not taken from the wrong location for example), and make comments/recommendations on what is being revealed. As each specialist performs this 'filtering', an overall picture of equipment health will be formed and made available for general consumption. Any user can now look at any of the supporting data, and over time, become more experienced.

Over time, with the right tools, users will look at information rather than data - this is the ultimate goal. For example, rather than looking at vibration spectra, non specialists should look at information describing the severity of individual faults in the equipment, with the final conclusions. All technologies should be handled this way.

MAINTENANCE MANAGEMENT SYSTEMS: One of the trickiest questions is where to draw the line between the condition monitoring system and the computerized maintenance management systems (CMMS). The information flow is illustrated in Figure 7. This is a huge subject all by itself, but some of the issues are described below:

- Which system should be responsible for scheduling the tests?
- Which system should be the main source of machine condition information?
- At what point should information be handed to the CMMS in order to generate a work/inspection order?
- How should you get overhaul, oil change and other key information from the CMMS to the condition monitoring system?

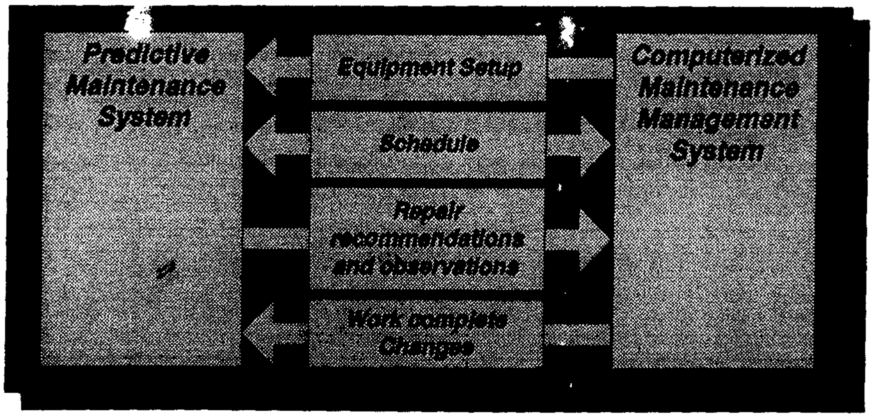

Figure 8: The link between Predictive Maintenance and CMMS

There is no clear answer to these questions. It seems every organization uses their CMMS in different ways. At one extreme users will state that their CMMS is inaccessible and unusable, thus the condition monitoring system should do as much as possible. Other users have excellent CMMS systems, and feel that the condition monitoring system should only be used to collect and diagnose data. The solution, therefore, is to support two-way links between the condition monitoring and CMMS system, and allow the end-user to utilize those links as appropriate.

WHAT DOES THE FUTURE HOLD? As far as the author is concerned, the future is in open, integrated systems. The days of proprietary systems with closed databases and limited functionality are numbered. The days of walking into a condition monitoring group office to find five computers, each exclusively used for a single technology, are numbered. This will not happen over night. Most users are loath to simply replace their existing system with the newest system on sale. So the first step is to begin the migration to an integrated system with just two technologies. Once some of the benefits of the change are realized, addition changes can be made. With cooperation within the industry (all condition monitoring users and vendors), all systems will be able to work together, either to support the transition of a site from one vendor's system to another, or to support the wide spread use of the key data.

With the move to open, integrated systems will come greater success in condition monitoring. With greater success comes greater visibility, viability and acceptance - something that is lacking in condition monitoring today.