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MASTER THESIS FOR THE AWARD
OF
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THESIS TITLE:
CONDITION MONITORING (CM)
IN
INTEGRATED OPERATION (IO)

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ABSTRACT

Outsourcing and remote monitoring are major industrial trends that provide an ideal platform for operators to focus and improve their core activities while saving cost. These trends have led to technological advancement which has improved oil and gas operations not only in terms of cost but also in terms of technology, competence and workforce management which is a major challenge facing the oil and gas industry. The shortage of skilled personnel, the ageing workforce amongst other challenges such as the need to maximize and improve depleting resources and HSE issues respectively has led to the emergence of integrated operations and its application in production, drilling, HSE and operation and maintenance or e-maintenance. E-maintenance or advanced condition based maintenance(CBM) is currently gaining acceptance by most operators and recommended by the regulatory bodies alike as they seek to find solutions to these challenges facing the oil and gas industry.

This thesis report on Condition Monitoring in Integrated Operation serves as a CBM application and technology indicator for implementing integrated operations or e-maintenance on the Norwegian Continental Shelf and beyond. It addresses current CBM technologies and equipment capable of achieving the intended e-maintenance objectives along with other supportive structures such as information standards, enabling technologies, expert requirements and IO centers which enable proper coordination and utilization of people, organization and technology. Furthermore, it addresses the current market and technology trends in condition monitoring, the market for smaller or non-critical equipment and the probable drivers and limitations towards the acceptance of condition monitoring which is vital for e-maintenance.

Analysis was conducted based on data and facts from industry, articles, journals, personal inputs and observations and is most suitable for condition monitoring vendors and operators adopting an integrated operation O &M concept and as such will enable both parties to have a thorough understanding of the necessary infrastructures both in terms of technical, social and psychological needed for the successful implementation of an IO-centered operation and maintenance activity. However sustainability of e-maintenance depends on the acceptance and implementation of standard information protocols capable of enhancing interoperability and data exchange between the various parties.

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I finally would want to dedicate this thesis to my parents,Mr and Mrs.Olakunle,my nieces and nephews-Amanda Udomba, Kamsie Olakunle, Paul Agbaje, Tobi Kjeldsberg Olakunle and the entire family for their support both morally, spiritually and financially. I love you all.

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CM: Condition Monitoring
IO: Integrated Operation
PdM: Predictive Maintenance
CBM: Condition Based Maintenance
DCS: Distributed Control Systems
OSC: Onshore Support Centers
BOP: Balance of Plants
CMMS: Computerized Maintenance Management Systems
WAN: Wide Area Network
LAN: Local Area Network
WSN: Wireless Sensor Network
NCS: Norwegian Continental Shelf
XML: eXtensive markup language
SOAP: Simple Object Access Protocol
WSDL: Web Service Definition Language
UDDI: Universal Description Discovery and Integration
WITSML: Wellsite Information Transfer Standard Mark-up Language
PRODML: Production Mark-up Language
SOIL: Secure Oil Information Link
VSAT: Very Small Aperture Terminal
RDL: Reference Data Library
WiMax: World Interoperability for Microwave Access
GPS: Global Positioning System

CHAPTER ONE

1.0 INTRODUCTION

Maintenance can be simply described as process of keeping plants, equipment and facilities in good operating condition so as to maintain the equipment efficiency and maintain or increase productivity. However, maintenance in the earlier days was viewed by operators and manufacturers as a necessary evil where a 'run-to failure' or reactive maintenance management approach was adopted such that equipments and plants were only attended to after failure resulting to production loss, downtime, unscheduled interruptions, and inevitable material, inventory, labor and other cost incurred in the repair process. As the views of the operators and maintenance experts became clearer they began adopting the preventive maintenance approach by scheduling maintenance practice on these plants and equipment based on statistical time data or average life statistics of the plants given by the original equipment manufacturers (OEM). This was also not a cost effective method due to the fact that the time of failure or mean time to failure of the equipment was known so most plants or components were replaced based on the stipulated OEM mean-time-to-failure data thereby neglecting those plants or components with possibilities of exceeding the stipulated date and this led to wasteful replacements. More so, different components have different mean-time-to-failure so do similar components with various functions i.e. the mean time to failure for a pump is different to that of a valve and so is the mean time to failure of a pump required to transport water compared to that required to transport crude oil, therefore maintenance experts were faced with challenges of having to make unnecessary repairs for components during scheduled maintenance periods or shutdown periods.

However, the major reason for the unnecessary repairs and replacements or use of statistical time given data for maintenance activities was as a result of lack of relevant data needed to define when and what kind of maintenance activity is needed to maintain, repair or replace components, equipment and systems within a plant. But the emergence of microprocessor based instrumentations brought about another era in maintenance management called predictive maintenance which involves monitoring the operating conditions of critical equipment such as pumps, compressors etc from which the data derived is used to plan and schedule maintenance tasks to prevent premature failures, reduce their life cycle cost and furthermore extends the useful life of these critical industrial assets. Therefore the emergence of condition monitoring of critical equipments in today's industrial sector has changed the negative perception viewed by most operators and manufacturers as regards maintenance. Condition based maintenance is now seen by most operating companies, manufacturers and maintenance experts as the ideal tool to optimize profits, save cost ,improve competitiveness and meet the strict and challenging safety and environmental legislations been implemented in the current industrial environment. This technique is currently undergoing various transformations and improvement in terms of products and services i.e. from the advancement in condition monitoring equipment and technologies, a shift to business to business (B2B) function between suppliers of the monitoring technologies and the end-users, integration of both historical equipment data and monitoring data and finally advancement in enabling technologies such as Information and Communication technology and wireless technology which has led to a new concept in the oil and gas industry today, a concept known as Integrated Operations with an economical potential of 250billion NOK over a ten year period from 2005-2015(OLF, 2007).Integrated Operations can be simply defined as new work processes driven by information and communication technology that enables the transfer and exchange of real time information or data across organizational, geographical and professional boundaries thus enhancing collaboration for better and faster decision making. In literal terms it can be seen as the 'globalization' within the oil and gas industry.

The thesis therefore provides insight on the recent condition monitoring technologies and equipment being used in the industry, their trends in the current industrial market and probable application of both condition monitoring technologies and IO-enabling technologies in Integrated Operations. Furthermore, it identifies possible ways in which the condition monitoring vendors can also add value to the IO concept.

1.1 INDUSTRIAL PROBLEM AND CHALLENGES

Integrated Operations (IO) is a recent initiative taken by the oil & gas industry in order to further optimize performance of people, organizations and technology to enhance HSE levels, production and efficiency. This thesis was conducted in collaboration with Petrolink AS, an engineering and technology service provider to the Norwegian Oil and Gas industry and abroad. It provides in-depth analysis on how Petrolink and other technology service companies can explore latest technologies suitable for integrated operations, the new roles and responsibilities these companies are expected to occupy and recommendations for efficient take off of e-maintenance.

Petrolink is a Norwegian technology company offering a wide range of specialist services to the oil & gas industry worldwide with main focus on pre-operations and operations of production and treatment plants onshore and offshore which consists of:

- Operations support,
- Engineering services including Integrated Operations,
- Project services and
- Facility management.

The company keeps high attention to enhance health, safety, environment and quality (HSE&Q) levels, cost optimization and well-tuned interaction between people, organization and technology which is a key driver in Petrolink's IO offerings.

Petrolink's ability to integrate across various disciplines, such as maintenance, being one of its core services, has identified a need for further research into the following areas:

- Recent developments of condition monitoring equipments and technology, a predictive maintenance technique, and its practical application in an IO concept.
- Consideration of the monitoring equipments and technology used for rotating, reciprocating and static equipments.
- Analyzing of the link between the equipment vendors and the IO value chain, the vendor standardization with respect to integrated operations with recent projects of interest such as the Eni Goliat and the British Petroleum Valhall Re-development (VRD) project case studies.

1.2 PROJECT SCOPE & TASK:

The purpose of this project is to consider the evolution of condition monitoring and its application with respect to the development of Integrated Operations (IO). To be able to achieve this purpose the following tasks were required to be undertaken:

- Perform a market survey of current condition monitoring equipment and technology.
- Identify where the market and technology is moving to.

- Assess the suitability of both today's and the future condition monitoring technology for IO applications.
- Identify where and how the condition monitoring vendors can become directly part of the IO value chain.
- Recommendations on the application of condition monitoring equipment in IO applications.

1.3 METHODOLOGY

The survey on the present condition monitoring technology was based on the 7^{th} Biennial ASME conference for engineering systems and analysis that was held in 2004(ESDA 2004-58216).The authors made up of prominent and distinctive scholars from both the academia and the industry employed the use of a suitable maintenance web hosting site www.createsurvey.com to conduct this survey with responses from industries in fifteen different countries ranging from the Middle East Africa, Australasia, South East Asia, Americas, Japan and Europe thus making it an authentic and ideal reference. Though the site was cost-free, conducting my own survey was faced with daunting challenges such as time limitations for advertising my survey which led to limited response from most respondents but however I underwent further research into acquiring the latest condition monitoring equipment and technology with the aid of the internet so as to make up for the five-year technology gap from 2004 to present day. The use of the various search engines, plant maintenance sites, seminar papers, presentations and other articles from internationally renowned maintenance authors were put into effective use in developing this thesis. Furthermore the IO standardization document was used to provide details into specific roles and responsibilities the condition monitoring vendors are expected to partake most especially in the conceptual design phase of an integrated condition monitoring project.

CHAPTER TWO
CONDITION MONITORING

2.0 DEFINITION

Condition monitoring is simply defined as a predictive maintenance or condition based maintenance technique which involves the continuous analysis of operational equipment and the identification of problems before component breakage or machine failure. It involves collecting and interpreting data and information that will be suitable for assessing equipment and component conditions not only to prevent breakdowns but in order to conduct condition-based preventive maintenance programs and can be said to be both a technology or product oriented practice in terms of equipments and software and a service oriented maintenance practice.
Condition monitoring comprises of various technologies used to monitor and analyze machine or equipment conditions. These technologies include the vibration analysis, Infrared thermography, oil analysis, thermodynamic monitoring, Ultrasonic testing, and recent advanced techniques such as motor current analysis etc.

2.1 HISTORY AND IMPORTANCE OF CONDITION MONITORING

Strip chart or circular chart recorders were used before and during the early 70's to record plant and machine data with which they were then compared with previous charts to assess the machine or equipment conditions. It was a time consuming process with inaccurate results. With time came the emergence of the computerized data acquisition system or microprocessor instrumentation in the 80's which made data comparison much easier, accurate and faster (Ghate, n.d.).And with time a new era of condition monitoring evolved with the emergence of vibration sensors, transducers and other smart devices with the major breakthrough being the computer system that was able store large amount of recorded data.
The marine industry was said to be the first to accept such a concept due to a research on finding out the detailed failure modes of the components of a ship's diesel engine which further led to the design and application of sensors. From 1969-1975, computerized monitoring systems with diagnostic methods were developed i.e. systems capable of analyzing and trending data. Further into the late 70's the development of micro-chips and improved sensor reliability brought about not only a breakthrough in micro-processor and portable micro-computers but an overall improvement in condition monitoring systems.

Condition monitoring is now a household name in the maintenance world. It is now used extensively in various industries ranging from cement, energy, petrochemicals and steel, paper and pulp industries and is becoming an important asset management tool to address the business need of these industries such as cutting maintenance cost, maintaining quality, increasing productivity, health safety and environmental control, beating off competitions etc,. Therefore the condition monitoring market has a huge potential for future growth as end-users are constantly adopting and implementing this program for its facilities to address its needs. Vendors and suppliers are also undergoing intensive research into innovative and improved monitoring technologies capable of achieving the demands and business needs of its clients. Condition monitoring has been of primary importance and a choice to most industries from the heavy industry using expensive and sensitive equipment like the rotating and reciprocating equipment to the light industries using mostly static equipment and machineries. In summary the importance of this maintenance technique is discussed below:

- **Reduction of maintenance costs:** Condition monitoring enables early identification of equipment failure which can be very costly in terms of downtime, material, labor and environment cost therefore enabling the maintenance experts to carry out repairs or replacement on the faulty component or part of the equipment. This is far cheaper compared to when the machine fails which could have a domino effect on other parts of the equipment or lead to a secondary damage. This early detection of fault has helped maintenance experts to effectively and efficiently plan and schedule maintenance programs, minimize material, labor and avoid unplanned downtime of equipment which may result in loss or deferral of production and income
- **Increase equipment lifecycle:** Corrective action implemented during fault detection will increase the life span of the equipment and its utilization.
- **Reduction in inventory cost:** Rather than having the normal scheduled maintenance shutdowns which always results in replacing component parts that are still functional thus leading to a high spare part inventory and purchase cost, condition monitoring has enabled reduction in spare stock holding since only the faulty components of the equipment are replaced. More so, components or parts with long lead times can be ordered well in advance since spares are ordered to suit shutdown periods. This can reduce inventory cost which could possibly inflate with time.
- **Improvement in personnel safety and reduction in risk**: Early detection and repair of faulty equipment has led to an increase in the safety of personnel such that catastrophes and possible hazardous events that could arise from these equipment failures have been curbed. Condition monitoring has further reduced the risk present in the working environments and thus a boost not only to productivity of the workforce but a decrease in litigation cost, hospital cost and compensation cost in the event of accidents.
- **Reduction in insurance premiums:** Insurance firms have recognized that there is a reduction in risk and safety improvement when condition based maintenance programs are applied in a facility thus these firms are now reducing the premiums charged on the equipment and facilities. These premiums are extremely expensive depending on the equipment and thus such price reduction is of great important to the client employing this technique for its facility.
- **Improved scheduling of maintenance programs:** Improved awareness of plant conditions with the use of condition monitoring enables proper planning of shutdown periods. During this process, maintenance experts can conduct a holistic maintenance program for the entire plant facility or equipment, rather than repairing only the faulty equipment other components or equipment can be

assessed therefore saving time and resources in the process. Furthermore shutdowns can be confidently extended.

- **Product Quality testing:** In recent times, monitoring equipment has now been used not only for monitoring but also in manufacturing processes for quality testing and control of products. For example in the steel industry, it is been used to detect incipient flaws on the surface of cold rolled mills.

2.2 INTEGRATED OPERATIONS-DEFINITION AND SCOPE

Integrated operations on the other hand can be termed real time operations or in the context of condition monitoring can be termed e-operations-e-maintenance. Apart from the utilization of ICT and advanced technologies, it involves the integration of ideas across numerous disciplines to create a reliable knowledge and information base and also the restructuring of organizational structures and work processes to maximize manpower and promote efficiency. E-maintenance involves predictive prognostics and condition monitoring of equipment of which the derived data or information is used for e-operations i.e. remote diagnostics, simulation, decision making, asset management and remote optimization. Achieving e-maintenance involves the use of telemaintenance principles, web-services and modern e-collaboration principles which enable data and work process to be shared easily (Iung and Marquez, n.d.). Telemaintenance refers to technologies that support the electronic transfer of information or data between the maintenance team or experts and the remote resources in order to perform e-operations such as remote diagnostics. It consists of enabling technologies or equipment such as phones, computers, video cameras, monitoring equipment that senses and reports performance, wear or other data thus providing the necessary feedback or even remotely carrying corrective adjustments or optimizations. These web services describe a standardized way in which web based applications can be integrated over the internet different methods such as extensive markup language (XML) which tags the data, simple object access protocol (SOAP) which transfers the data, web service definition language (WSDL) which describes the services available and universal description discovery and integration (UDDI) which provides the available services offered by the vendors or experts to the end-users. E-collaboration on the other hand is simply sharing and exchanging information, knowledge and expertise through enabling telemaintenance technologies (emails, Instant Messaging (IM), video conferencing etc) which could link these information between collaborators either from the vendor-to-vendor, maintenance expert-to-expert, expert-to-client, client-to-client etc.

Therefore the major application technologies enhancing e-maintenance are the wireless networks, internet technology, sensor technology, pervasive and intellectual computing and the industrial information integration. (Liyanage et al, 2009).A holistic view to the sharing and transfer of data and information defines e-maintenance-e-operations. Implementation of this concept will lead to changes in most organizational work process and structure which will promote efficiency, reduce cost, and maximize resources and proper utilization of manpower within and across organizations.

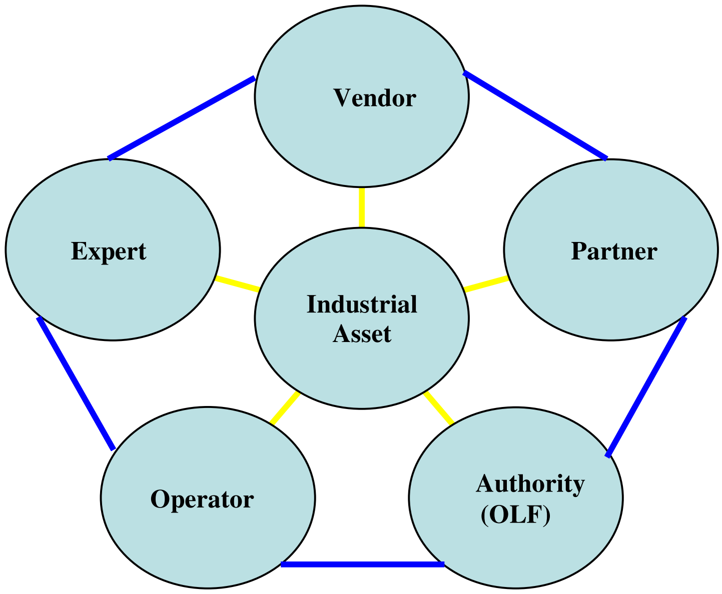


Fig. 1.0: communication pathways: the future of Integrated Operations

Keys:

E-collaboration. Telemaintenance.

2.3 HISTORY AND EVOLUTION OF INTEGRATED OPERATIONS-IO DRIVERS

The name 'Integrated Operation' was culled from the Norwegian operator (Statoil Hydro) operating in the Norwegian Continental Shelf (NCS) and has been in use previously by different operators in the oil and gas industry under different names such as e-Operations (Hydro), Smart Field (Shell), Field of the Future (BP), and intelligent field or i-field (Chevron) even though the names are different but the concepts are similar. It dates back to 2004-2005 when the Norwegian oil industry association (OLF) under a re-engineering process to integrate operations which could save cost and increase their revenue on the NCS to $41.5billion of which failure to undergo such a task could lead to potential loss of $10billion within the next three years(Vartland et al, 2007).The development plan began in 2005 from developing new and smart solutions for O &M, seeking long term transformations to the traditional O &M practice and are now faced with the current plan of realizing fully functional e-operation status by the 2012-2015.(Liyanage, 2009).It has now provided operators with opportunities for developing maintenance types and cost effective strategies, improving maintenance support tools and data-dependent support systems, defining new maintenance activities and is now geared towards achieving a zero-downtime performance (Liyanage, 2009).

The illustration below gives a summary of the key drivers of the e-maintenance concept from the advancement in ICT and innovative technologies to the utilization of remote monitoring of industrial facilities. Technological advancement have forced most end-users or operators to outsource their non-core activities so as to focus on its core areas and in the process save cost in terms of R&D investment in equipment, software, expertise and personnel development etc while outsourcing on the other hand has led to rapid advancement in technological solutions to meet the changing needs of its clients which is a key sustenance tool. These end-users are able to get access to these technologies without major investment since it is not their core business leaving the challenges and tasks associated with R & D to the vendors.

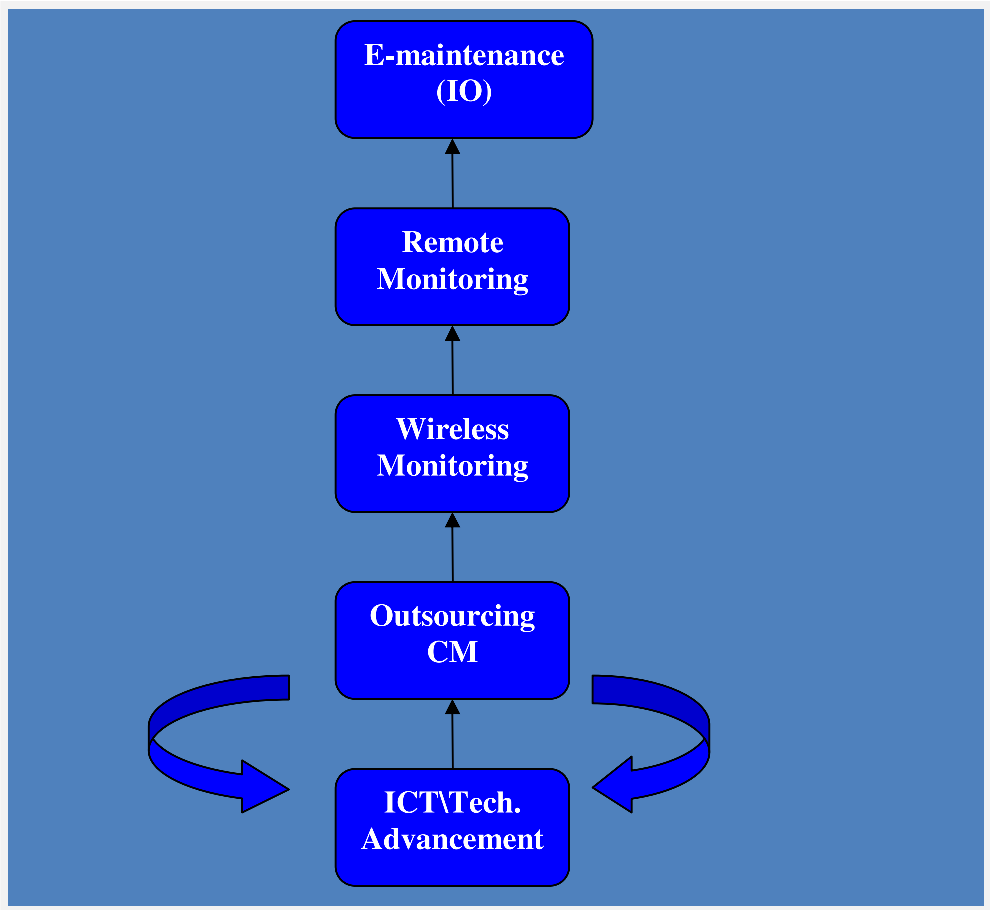


Fig. 2.0: Gradual emergence of Integrated Operation in the O & M. (IO DRIVERS)

In recent times, the industry is now experiencing stricter environmental and safety laws coupled with exploration and production challenges such that the earlier days of discovering cheap oil is over and there is a surge towards exploring difficult terrains such as the arctic regions and deep waters. Operators are thus faced with not only exploration and production cost but the cost of also operating and maintaining the facilities and thus see the need of sharing information and data not only between themselves and their business partners but also between other operators in the industry.

2.4 CONCEPT IN INTEGRATED OPERATIONS

Over the years integrated operation has been undergoing restructuring. The concept has evolved over time from limited integration to integration across core disciplines where there is a shift from the traditional process of self-sustainable fields to the present trend in IO of ongoing integration of onshore and offshore centers and continuous onshore support. Integrating across onshore and offshore centers with the continuous onshore support defines the generation 1(G1) which is currently been adopted by most operators in the industry. The concept is such that in order to hasten work processes and improve onshore support, most vendors would need to move closer to the assets either by establishing offshore support centers (OSC) and linking it with its clients (Vendor Center-to-Operator Center) or establishing a joint IO center which consists of experts with multidisciplinary skills, this is the generation 2(G2) phase. The G2 will involve heavily automated processes, integration across various organizations and an around the clock operation. This integration across organization will certainly involve reorganization of work processes where most organizations will have to restructure and increase the competent level of its workforce most especially in line with the emerging trends in innovative technologies such as sensor, ICT etc.

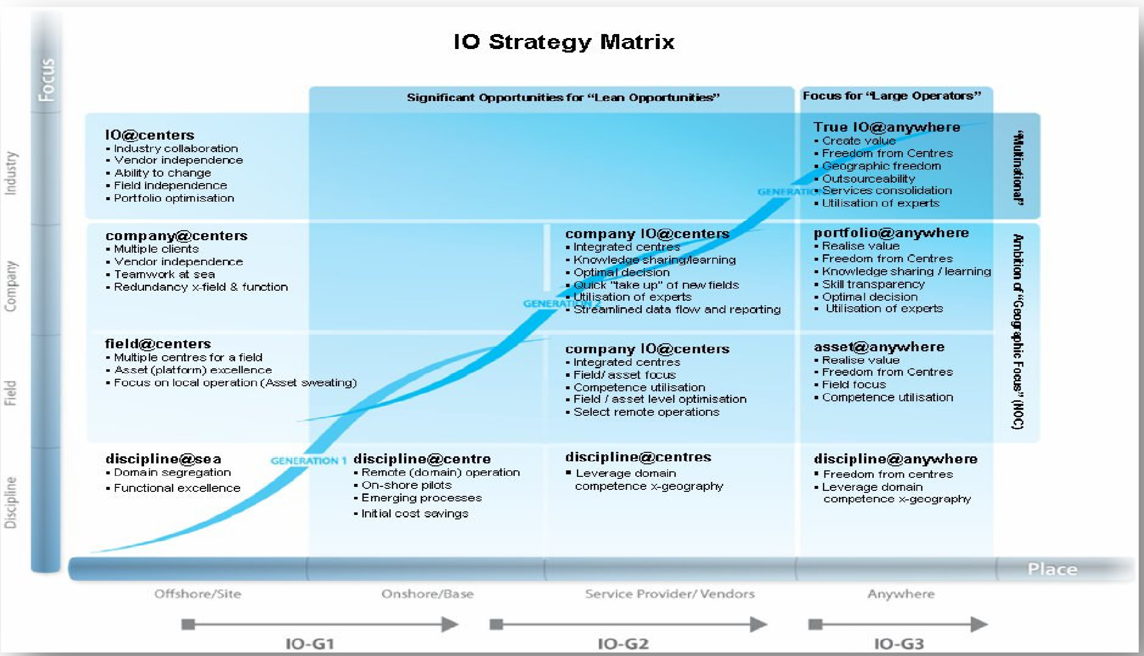


Fig 3.0 Concepts in Integrated Operation (Konda and Evensen 2008)

OLF defined these IO transitions into two stages, generation 1(G1) and generation 2(G2) with each generation have specific characteristics and would require different operational philosophies in project development with the generation 2(G2) being the initiation phase which gives the monitoring vendors total access to be part of the decision making process in operating the facilities. However, the ultimate stage should be such that creates value from its assets rather than realizing, an attribute common to G1 and G2 and that means rather than having centers, IO can be done anywhere by anyone with the use of highly networked organizations and can be characterized by a high degree of collaboration and innovative use of technology to create and realize value from its assets. Konda and Evensen (2008) defined this as the generation 3(G3) phase or IO@anywhere which is characterized by freedom from the OSCs, location freedom and high level of competence utilization with interoperable systems. Though the G3 stage seems more like fantasy but cannot be completely ignored judging from the current state of technological breakthrough and advancement.

2.5 CONDITION MONITORING IN INTEGRATED OPERATION

In the Norwegian oil and gas industry, the objectives of establishing or building up integrated operation and maintenance plan was based on challenges and opportunities to improve the oil and gas industry in terms of efficiency, productivity, safety and security(Liyanage et al, 2009).Key opportunities and challenges were to be addressed and they include:

- Compensating for shortage of skilled and experienced operation and maintenance personnel by creating new organizational structures where knowledge can be easily transferred.
- Enhancing communication and cooperation between different stakeholders by standardizing the technical language between the stakeholders.
- Implement more robust technical platforms for effective operation and maintenance data management.
- To try out and implement new technological solutions capable of enhancing predictive maintenance capabilities.
- To create an active network capable of enhancing decisions and activities.
- For easy and fast accessibility to data or information for the experts in emergency situations.

The technological solution to addressing these challenges would require coverage on three key areas: autonomy, automation and collaboration.

- **Automation**: A key factor towards realizing full IO potential though could act as a limiting factor for Brown fields such as the upgrading of the existing facilities of BP-VRD towards achieving integrated operations and must be fully integrated from conception for Green fields such as the Goliat project and part of the BP-VRD which is to be newly developed. It involves the use of advanced monitoring tools and technologies to enable remote operations, remote performance measurement, remote field optimization etc that enhances the removal or limiting of the human intervention from the loop.
- **Autonomy:** Technologies able to promote autonomous actions**-**Independent thinking or decision making, situation awareness, representation of abstract concepts for easy comprehension.

- **Collaboration:** Collaboration between the respective parties in the project or operations phase for the purpose of joint situation awareness, collaborative decision-making, collaboration between organizations to develop standards etc

These three key areas would require development and utilization of technological solutions in wireless communication and sensor technology, robotic or automation technology, collaborative visualization tools and corporate decision support models. Therefore addressing these technological areas will provide a solid platform for an integrated condition monitoring process

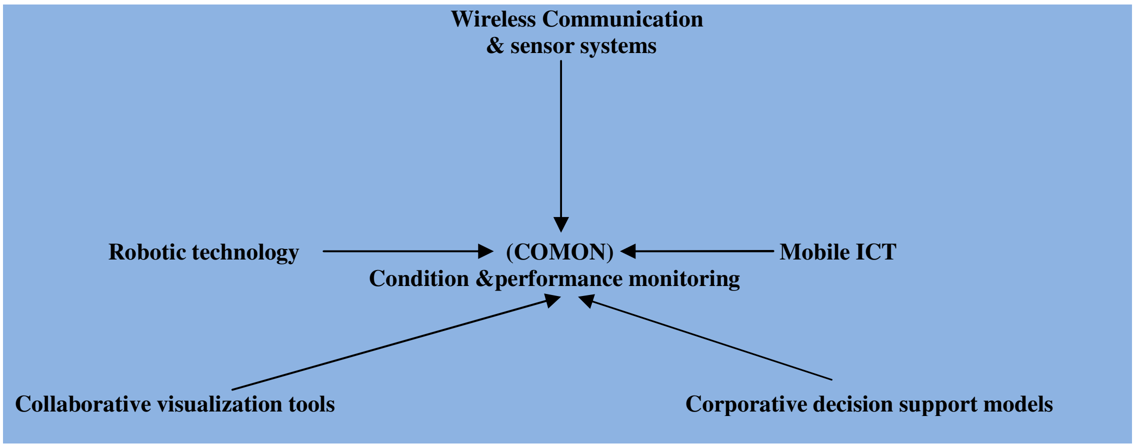


Fig. 4.0: Technological Solutions for CM in IO

The above six technological solutions have been the key focus of a pilot project known as TAIL-IO which is been conducted to improve Statoil Hydro's field operations mostly during the tail end of production because most fields have reached this stage so implementation of the project is necessary to avoid wasting resources. The TAIL-IO project is under the auspices of Statoil Hydro with a consortium of companies such as ABB, SKF and Aker Solutions with ABB in charge of the R &D project and financial support from the Norwegian Research Council (Vartland et al, 2007).The project lies in:

- Using wireless communication and sensor systems to design an open communication system and promote remote condition monitoring;
- The automation of maintenance tasks to reduce man-hours;
- The use of mobile ICT to enable continuous access to support systems and personnel via wireless connection and PDAs;
- Use robotic or smart technology to develop solutions that combine tele-robotics and advanced visualization to enable remotely operated inspection and maintenance operations as well as to identify and close technology gaps;
- Developing corporate decision support model for strategic planning of shutdowns and turnarounds to develop a tool that can accommodate a vast and complex range of data with the ultimate objective of eliminating asset shutdowns.
- To finally using collaborative visualization tools for preparing, training, executing and supporting maintenance operations. This tool would be able to support a wide

range of functions from multi-organizational team collaboration, performing maintenance operations and diagnostics and improve the level of assistance from centers of excellence or onshore support centers. (Vartland et al, 2007)

CHAPTER THREE
MARKET TRENDS AND SURVEY OF CONDITION MONITORING EQUIPMENTS AND TECHNOLOGY

3.0 MARKET OVERVIEW & TRENDS -SERVICE AND TECHNOLOGY SEGMENT.

According to a recent survey conducted by Frost and Sullivan research (2008), various industries from the heavy industries to the light industries are now accepting condition monitoring services and technologies as the most efficient means of maintaining and maximizing their asset health and performance and has thus contributed to the continued growth of the world condition monitoring equipment and services markets. The survey estimated a compound annual increment of 8.7 % in unit shipment of condition monitoring equipment from 35,800 in 2002 to 64,400 in 2009 and subsequently a 9.2% compound annual growth rate in total revenue from $383.6million in 2002 to $711.3million in 2009.From the doubled annual growth rate we see that condition monitoring is now a huge market which is likely to increase in the future as more industries and regulatory authorities are adopting this predictive maintenance technique. Therefore the graph below shows the increase in demand and accrued revenue from the condition monitoring markets from 2005 to 2008.

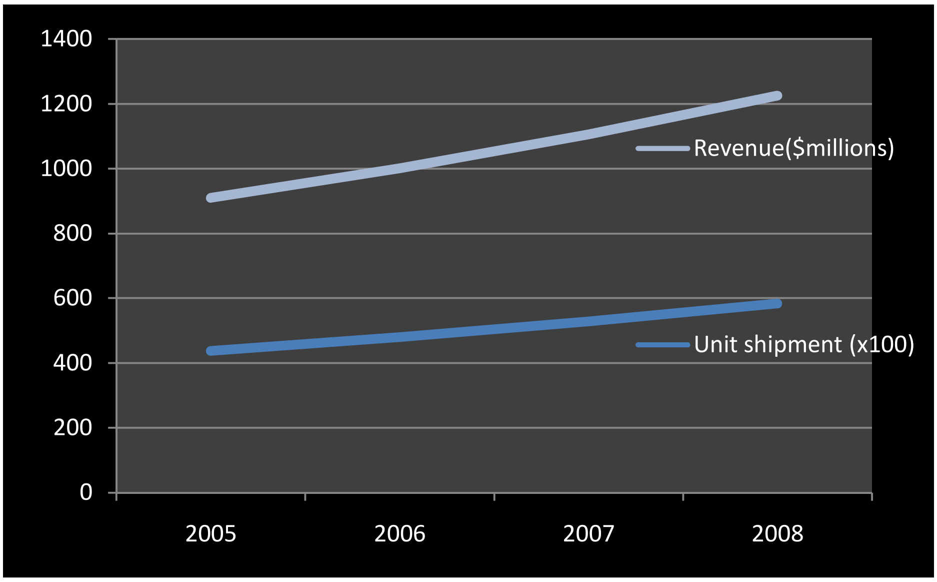


Fig. 5: Graph of Unit shipment \Revenue (Data source: Frost & Sullivan 2008).

The current condition monitoring market consist mainly of vibration monitoring equipment, lubricating oil analysis equipment, thermography equipment and finally the rapidly expanding consulting and services market. Other markets exists such as the corrosion monitoring which is gradually emerging most especially in the North Sea due to the challenging operational conditions during oil and gas production, most especially in pipelines during gas production as a result of variations in process parameters .Other reasons for emergence of corrosion monitoring market include implementation of strict safety standards and cost pressures due to global competition of which in the process industries alone, corrosion cost is said to be worth $50billion per annum with an expected increment over a five year period (Kane and Briegel, 2007) i.e. a promising market to explore. Furthermore new developments in corrosion monitoring are geared toward real-time monitoring (corrosion data can be integrated with vibration and process control data) and has expanded the corrosion market both in terms of services and products i.e. offering corrosion monitoring programs and sale of corrosion monitoring equipment. However, the bulk of the market is still limited to the petrochemical, pharmaceutical and oil and gas industries only.

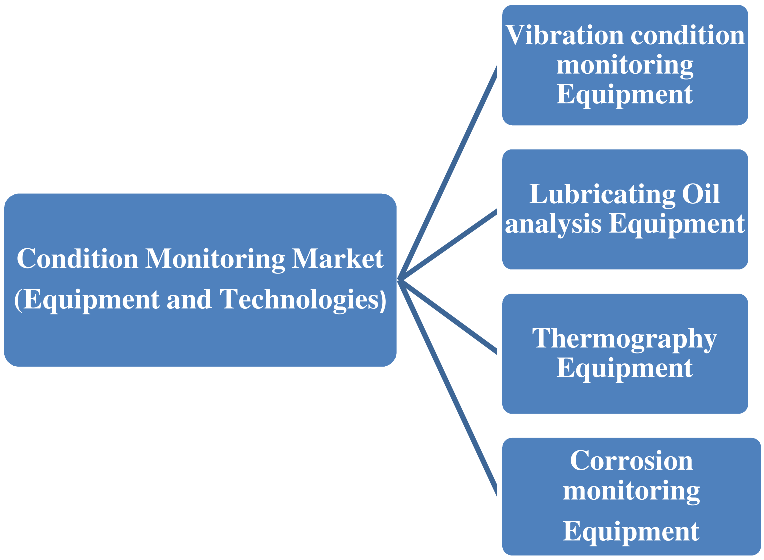


Figure 6.0: Current condition monitoring markets for equipment and technologies (Frost and Sullivan, 2008)

Vibration monitoring equipment currently occupies the condition monitoring market and from observation in ***figure*** *7* below it has been in demand till present day since 2002 unlike the demand for lubricating and corrosion monitoring equipment which has gradually decreased maybe due to unforeseen market forces or the recent economic downturn. Furthermore, vibration equipment are been used in different industries compared to these monitoring equipment which are still specific to certain industries and might account for the steady market demand amidst the economic constraints. The service market on the other hand involves mainly developing and implementing monitoring programs, vibration monitoring services, oil analysis, thermography and corrosion services to the end-users.

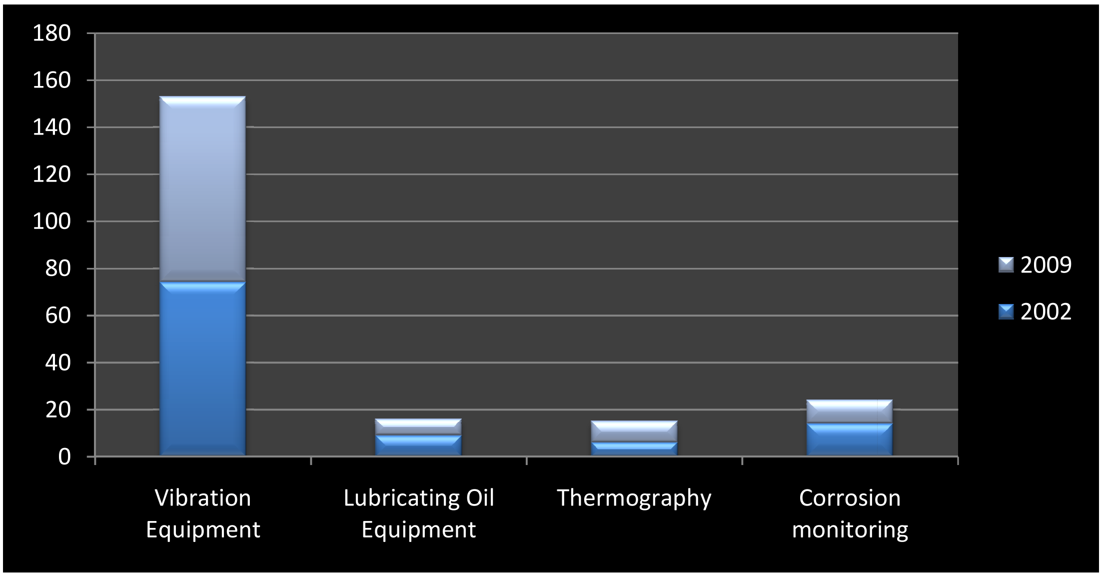


Fig. 7: Unit shipment of condition monitoring equipments and services in percentages (%) (Data source: Frost and Sullivan, 2008)

The above analysis conform with the survey conducted by Philip et al in 2002 and 2004 respectively with vibration analysis, oil analysis, and thermography in the order of demand by industries across the globe.

3.0.1 OVERVIEW OF VIBRATION MONITORING EQUIPMENT MARKETS

Vibration monitoring instrument consists of portable or permanent equipment. The portable equipment consists of simple data collectors which could be handheld to advanced systems with sophisticated software and are mostly used for periodic monitoring while permanent equipment are online vibration monitoring systems consisting of permanently fixed sensors integrated to output devices like monitors etc. It is capable of collecting vibration data at different sensor points and is most suitable for continuous monitoring of equipment and is thus seen as the ideal e-CM tool for today's O & M activities. Vibration monitoring has emerged as the best established and widely accepted technology for condition monitoring amongst other monitoring techniques due to the fact that a large number of service providers and end-users are largely involved in this technique. The reason for this is not farfetched and can be traced to the fact that all manufacturing units depend on machines. These machines operate at natural frequency at which any deviation from this frequency indicates a probable fault in the machine. Therefore judging from this fact, most vendors are venturing into manufacturing vibration products (portable handheld data collection equipment to large-size permanent installed vibration monitoring systems) and as at 2007, vibration monitoring systems was said to have generated the largest revenues for these service providers and equipment manufacturers thus accounting for 64.4 percent of the world condition monitoring equipment revenues. (Frost and Sullivan, 2008).

Furthermore rather than the conventional usage of the portable handheld data collector and monitors, most manufacturers are having these products built in their equipment (online equipment) which is gaining more patronage in today's markets. According to the Frost and Sullivan reports (2008), the following trends were observed in the vibration monitoring markets:

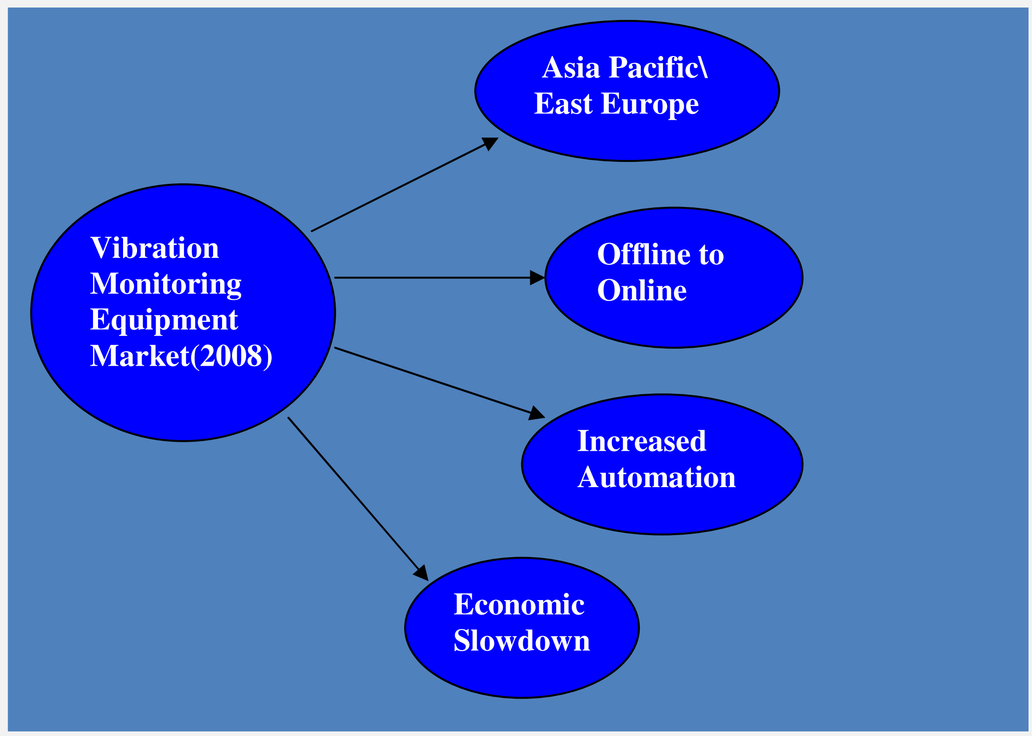


Fig 8.0: Trends in vibration monitoring equipment.(Frost & Sullivan, 2008)

1.0 Shift in manufacturing of vibration monitoring equipment to Asia pacific\Eastern Europe

The manufacturing base of vibration monitoring equipment are now shifting to regions of Eastern Europe and Asia pacific regions where the cost of operation and production is low i.e. cheap labor and availability of expertise and skilled personnel and has subsequently lead to the proliferation of monitoring equipments especially vibration equipments. This has contributed to a significant drop in equipment cost generally forcing monitoring companies or vendors in North America and Europe to lower their cost. The current market is now open such that there is an entry barrier for the smaller vendors because the market is divided into many regional players and a small number of global players which dominate the market. This market consists generally of large public and privately owned companies such as the smaller vendors offering both vibration monitoring services and products to end-users. The big players include SKF Condition monitoring, Rockwell Automation Entek IRD, Vibrometer SA, Thermo Electron Corporation, and PerkinElmer, Spectro Inc,Emerson process-CSI,Bently Nevada(a subsidiary of GE) etc. However, the proliferation and success of the smaller vendors in the market can be seen from the vast number of end-users applying vibration monitoring to monitor their equipment as compared to other monitoring techniques. This has been a key to their sustenance and survival. End-user industries like the power generation industry, the marine industry, pulp and paper, the oil and gas industry, mining industry etc are now using vibrating equipment for monitoring their heavy equipment.

2.0 Offline monitoring to online monitoring

There is a tremendous shift from the traditional offline monitoring to online monitoring. Online monitoring systems have now been proven to reduce maintenance repair costs for example the Bentley Nevada online monitoring system capable of monitoring both critical equipment like the rotating and reciprocating equipment and essential equipment like pumps. The use of permanent online monitoring systems has been of immense benefits not only in reduction in maintenance cost but time saving in terms of less overtime and standby time, less unscheduled night calls etc for instance rather than manually collect vibration data for longer intervals of say every 15 days, amplitude levels can be collected every 10minutes.An example is the Bentley Nevada online monitoring system on now been used by most industries such as the BP-Valhall. It is integrated with a data manager (DM) 2000 system software capable of capturing and displaying information or data on the mechanical condition of the critical equipment, a Trend Master(TM) 2000 which is a data acquisition system monitoring static or auxiliary components of machines and equipment. Both of which are connected through digital communications links TM2000 DDE (dynamic data exchange) and PI DDE interfaces to the Distributed Control System (DCS) so that the machinery information is accessible online through the desktop computers to operators. This online system is been adopted generally by most end-users as it is been seen as a cost effective system in terms of maximizing workforce and minimizing maintenance cost. Furthermore advancement in networking technologies and the availability of the internet has paved the way for remote monitoring from central or onshore locations.

3.0 Increased Automation

Novel technologies have further led to automated vibration systems where data sampling and analysis can be done automatically. This reduces the use of human labor and allows for timely maintenance in the process. Modern vibration models promote online and remote monitoring of equipment such that apart from its wireless support, it is now integrated with other monitoring or remote application technologies to enable real time monitoring of facilities. It is also capable of interfacing with existing alarm systems to provide warning of possible machine failures. Recent introductions include highly automated vibration modules capable of automatically analyzing vibrations in equipment and generating an automatic work order which is been sent to the maintenance system. Other inbuilt modules are capable of monitoring other parameters such as temperature.

4.0 Economic slowdown

The recent financial crisis is expected to restrict end-user spending and slowdown the growth of the vibration monitoring market as most end-users are trying to minimize cost and this would seriously affect the smaller vibration monitoring companies and a further reduction in the price of these equipments. Most users would however still require vibration monitoring equipment for their critical equipment but would minimize its usage for auxiliary equipment.

3.0.2 OVERVIEW OF THE LUBRICATING OIL ANALYSIS MARKET

The lubricating oil analysis equipment market is segmented into oil analysis (fluid properties and fluid contamination analysis) and wear debris analysis. Oil analysis is conducted in-line or offline. The latter is conducted in the laboratory and is often inaccurate due to exposure or settling from contaminants outside the lubrication system which alters the sampled data. Moreover the samples are often tested inconsistently thus making it difficult to identify changes before failures. The demand for in-line monitoring is now the preferable choice for maximizing the performance of equipment and its life cycle costs. Unlike offline equipment, the in-line equipment are portable and accurate such that they can take samples from the lubrication system through a sensor which collects and analyzes the data immediately while saving time in the process. These in-line equipments are new technologies of oil analyzers that are new in the market and still undergoing product improvements.

In terms of market, in 1999, 78% of the market consisted mainly of oil analysis equipment while the remaining 22% was wear particle analysis equipment. The latter experienced a 0.2% increase in 2002 thus indicating a high possibility of market expansion in the future with expectation of 24.7% by 2009 at the detriment of the oil analysis equipment expected to fall over the seven year period from 77.8% to 75.3% in 2009.(W.I.S.C, 2004).

3.0.3 OVERVIEW OF THERMOGRAPHY MARKET

The largest users of thermographic equipment are the power generation, transmission and distribution companies and nearly 75% these companies use thermography as a predictive maintenance tool. (Acuity Market research, 2006).It is simply used to locate electrical equipment that is hotter than normal and in recent times the technological improvements has been centered on the following properties: size, and power of the thermal imaging system, portability, increasing the thermal and spatial resolution to improve the image quality and other features. Furthermore there is a downward trend in cost of this equipment even as thermography equipment are being developed with higher performance thus giving smaller firms and businesses opportunity to be involved in this business for instance the lenses and the detectors are the most expensive parts of the Infra red thermometers but as a result of the mass production of IR detectors and new lens material for other consumer products, the high demand for these products and high production of standard sensors have driven the prices lower. This downward trend has led the bigger companies into buying and designing their own infrared thermal imaging cameras and thermography program respectively (Cronholm, n.d.)

According to Mikael Cronholm, an independent Swedish-based thermography contractor, the future of the thermography market lies in certifications which is now been adopted to curb the proliferations of thermographic experts in the industry. However, the main likely trends in the world thermography market should be:

- In-house: corresponding shift in know-how from experts to maintenance technicians in the application of this technology.
- The high demand for certifications in thermography.
- The affordable cost of these equipments i.e. low equipment cost
- The rapidly expanding applications of this technology for industrial maintenance even in the areas of medicine to detect cancer.

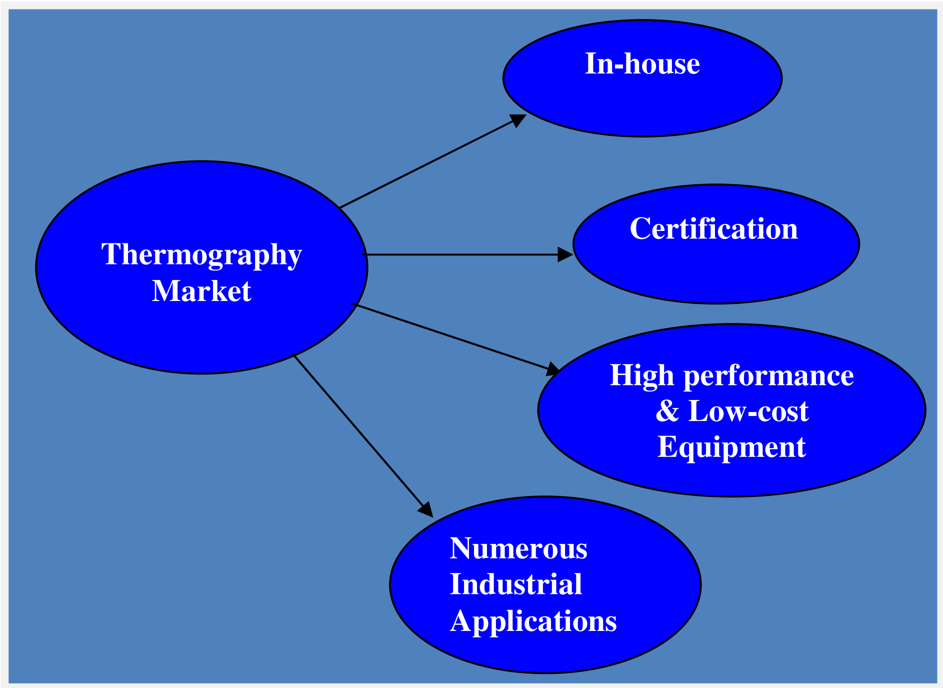


Figure 9.0: Market trends in World Thermography market

These four trends in the thermography markets are interwoven such that the decrease in the cost of infra red thermal imaging cameras has led to the big consumers such as the power stations and distribution companies, utilities and manufacturing companies to start buying their own cameras thus leading these companies to develop their own thermography programs in-house. This has led to experts and thermography consultants seeking the assistance of a third party which will promote the sale of this equipment in the market. The strategies adopted involve including the insurance companies in the supply chain such that you can also get access to infra red thermal imaging cameras through insurance companies or by using the insurance companies to endorse or recommend the use of thermography equipment to its clients. This has made the market successful since most clients are conscious of fire risk and hazards and highly regard such insurance companies.

In Scandinavia i.e. Sweden and Norway to be specific, in order to regulate these markets, experts and consultants have introduced certification systems for electrical thermographers with the support of their effective thermography organizations and the insurance companies such that certification provides the only access to selling or buying these products either indirectly from the insurance companies or directly from expert to consumers. In Sweden, organizations involved include SBF (The Swedish Fire Protection Association, involved in insurance issues and have insurance companies as members and is also a member of CFPA(Confederation of Fire Protection Associations), SBSC (The Swedish Fire and Security Certification Company, an Accredited Certification Body according to SS-EN 45013 responsible for the certifications), SWEDAC (The Swedish Board for Accreditation and Conformity Assessment, a Swedish public authority, responsible to the Ministry for Foreign Affairs) and also the first ISO 9001 certified infrared training organization in the world while the Norwegian counterpart is the NEMKO Termsert 01 which acts as a regulator to any interested person starting a thermography business in Norway. This organization therefore apart from regulating the markets through the issuance of various certifications such as ASNT, Infra red training center certificate (ITC) etc also promotes credibility in the business by ensuring that the certification bodies are following laid down standards and procedures.(Cronholm, n.d).

In terms of its numerous applications in various industries majority of its use has been for the detection of overheating components which complies with the survey that the power generation companies are the largest consumers as fore-mentioned above.

CURRENT USE OF THERMOGRAPHY	% CONSUMPTION
Detection of overheating components	73
Measurement of transformer temperatures	53
Identification of heat loss areas	43.7
Motor Inspections	36.7
Repair of electrical components	35.9
Identification of material wear	28.9
Monitoring of outdoor wiring	27.8
Building Inspections	23.3
Management of maintenance inventory levels	14.4
Roof Asset management	12.6

Table 1.0: Current use of thermography
(Electrical Construction and Maintenance magazine, 2009)

Therefore the illustration below gives a general summary of the market segmentation of the various monitoring technologies, equipment and services:

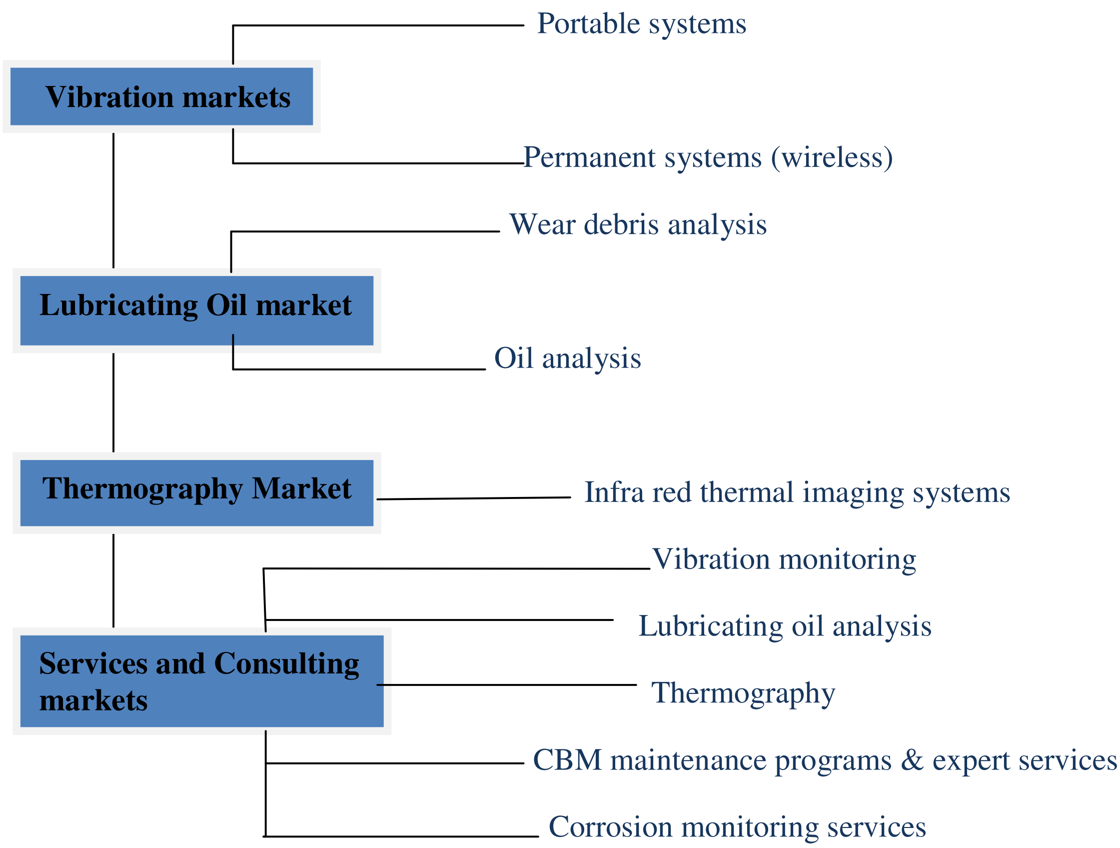


Fig 10.0: Market segmentation of Condition monitoring equipments and services

3.1 GEOGRAPHICAL ,END-USER AND SMALLER EQUIPMENT MARKET ANALYSIS

Furthermore, the end users for condition monitoring equipment and services have spurned from different manufacturing sectors such as the oil and gas industries, chemical industries, mining, food, paper and pulp industries etc but the oil and gas industry currently has the highest patronage of condition monitoring equipment and services a fact supported by the Philip et al market survey on monitoring equipment. However, other industries are emerging as major end-users such as the marine industry and the paper and pulp industry. Apart from services, majority of these condition monitoring companies are into product development and lately there has been a monopoly in the production of online protection systems of which General Electric (GE) Bentley Nevada has been the sole producer .This has given GE a comparative advantage over its competitors in the condition monitoring market. GE integrates its Bentley Nevada monitoring system with a protection system to help avoid costly and unexpected down-time and is been sold as a complete monitoring package to the end-users. Competitors like SKF have recently moved into the protection system market to break this monopoly with the introduction of equipment such as the DMx Multilog On-line System integrated with the SKF@ptitude analyst condition monitoring software capable of both monitoring and offering protection to critical and non-critical components or equipments alike.

Decline in the prices of condition monitoring equipments has encouraged end-users to invest in these equipment and technology, thus rather than use these monitoring technologies to predict component failure there has been a proactive approach towards improving reliability and performance. Vendor companies like SKF known for the production of bearings are therefore moving into production of reliability components or systems. With Asia as the emerging market for condition monitoring equipment supplying most of the products to the saturated US and Europe even though the latter is known as the major condition monitoring market in the world. Asia is now experiencing a high growth rate of monitoring equipment both in terms of services and product.

In recent times the industrial environment has experienced acquisitions and mergers as global vendors moved in to acquire smaller or local monitoring vendors and as a result of deregulation, high operational cost and increase in foreign direct investments in the popular condition monitoring markets, manufacturers are shifting their facilities to Asia Pacific, Latin America and Eastern Europe typical example is the recent moves by SKF to acquire companies in China, Korea and even in the eastern blocks like Ukraine. More so, according to Gary Mitchell the business manager for customer support in Asia pacific for Rockwell Automation, capital investments in infrastructural projects in this region has brought about the steady growth of the condition monitoring market such that industries in India, China, South east Asian countries like the Philippines, Thailand, Indonesia are now protecting their expensive critical assets used for such projects thus have adopted condition monitoring as part of their maintenance strategy. He further accentuated that even the non-critical assets or smaller assets i.e. the ‘balance of plant’ (BOP) maintenance service markets are expected to grow as most of the new plants in these areas are affected by wear and tear mechanisms which is a non-core activity for these industries and will require the services of tribology specialist, a non-core activity which will further boost the outsourcing market in Asia pacific.

However in Europe the market for smaller equipment monitoring is still at a slow pace since most end-users are adopting condition monitoring based on criticality analysis results of which the large equipments such as turbines, compressors are critical equipment and from cost benefit analysis, using a very expensive sensor for a small equipment such as a valve that is less critical is surely a waste of resources and moreover since the failure modes of most non-critical equipment are known, periodic monitoring is the best possible cost effective alternative. Therefore most producers of auxiliary components such as bearings, valves are keen on producing highly reliable products while end-users with the financial capacity to use monitoring technologies will likely select from the numerous components based on event tree analysis method. The large amount of auxiliary component needed to balance a plant alone could also limit the use of condition monitoring equipments to heavy equipments only.

The above geographical analysis was further supported by the recent geographical sales data from one of the major condition monitoring vendors, SKF. The pie chart below has Western Europe as its major consumer or end-user, the Asia pacific as the next upcoming market with Middle East and Africa as the least.

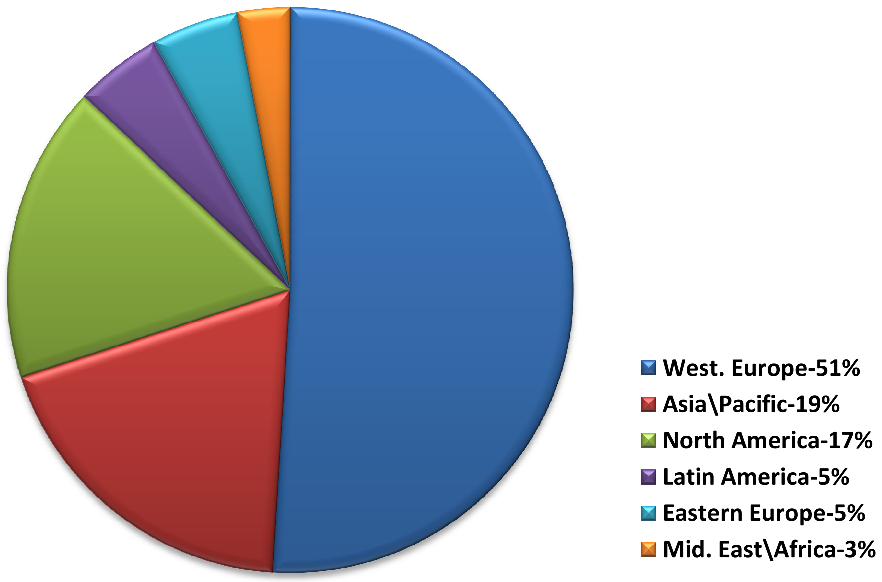


Figure 11.0: Geographical sales market-Product and Services (SKF, 2009)

3.2 CURRENT MARKET DRIVERS AND RESTRAINTS IN THE USE CONDITION MONITORING TECHNOLOGY

The condition monitoring market is now experiencing a boom due to the increasing awareness and acceptance of its technology and condition based maintenance programs and practices. It is being seen as the best possible means of getting maximum asset effectiveness from one's assets and at the same time with increasingly stringent safety and environmental laws being enforced by regulatory authorities, it is of no doubt the best possible way of preventing equipment failures which would lead to catastrophic consequences. The current drivers of condition monitoring technologies include:

- Industry standards like the NORSOK standards now recommend using condition based maintenance (CBM) methodology as the PdM along with other preventive maintenance techniques in their maintenance programs.
- Furthermore, technological advancement and wireless communication has become a key driver of the monitoring markets, its efficiency and low cost compared to wired systems or wired monitoring equipments is incomparable thus has enabled remote monitoring of machines, save cost of transportation to and fro offshore facilities, more reliable results etc

- Most industries like the manufacturing industries such as the iron and steel industries are realizing the business benefits of using condition monitoring technologies to assess the quality of their products rather than predict equipment failures.

However, the high cost of procurement, installation, operation and maintenance of some condition monitoring equipment such as the Bentley Nevada system and other expensive monitoring systems have restrained end-users such that they rather buy the function from the OEM than the equipment itself. Other restraints in the condition monitoring markets include:

- Proliferation of monitoring equipment which has led to a reduction in the overall prices such that due to strong competition most CM manufacturers are faced with no option than to lower its prices.
- The need to educate and train the users of these monitoring equipments by the end-users have also led to restraints and can be seen as one of the reasons why the service segment of the industry has received tremendous growth since the end-users would rather outsource and save the cost of employing and training its workforce.
- The run-to-failure management philosophy imbibed by some organizations such that they view condition monitoring as an expense and are not sure about the return on investments these technologies can bring.

3.3 SURVEY OF CONDITION MONITORING EQUIPMENT AND TECHNOLOGY

The survey on condition monitoring technology and equipment were divided into two parts, the first part consisting of current condition monitoring or NDT techniques while the second part is contained in an excel spreadsheet having the list of specific monitoring equipment and software present in today's industry with access to their respective vendors. The survey on the present condition monitoring technology was based on the 7th Biennial ASME conference for engineering systems and analysis that was held in 2004(ESDA 2004-58216).

TABLE 2.0: CURRENT CONDITION MONITORING\NDT TECHNOLOGIES

S\N	CONDITION MONITORING TECHNOLOGIES
1.	Vibration analysis
2.	Oil analysis
3.	Infra-red thermography
4.	Human Senses
5.	Motor Diagnostic techniques-Motor Current Analysis & Motor Current Signature analysis http://www.alltestpro.com/pdf/CURRENTSIGNATUREANALYSIS.pdf
6.	Dye Penetrant Examination
7.	Ultrasonic Thickness Testing
8.	Ultrasonic Crack Detection
9.	Magnetic Particle Inspection
10.	Acoustic Emission Analysis
11.	Wear debris analysis
12.	Alloy analyzer X-ray
13.	Strobe light\Light-Emitting Diodes(LED)
14.	Boroscope\Borescope
15.	Shock pulse
16.	Ultrasonic vibration
17.	Motor Operated Valve Diagnostic Testing
18.	Air Operated Valve Diagnostics Testing
19.	Check Valve Non-Intrusive Testing
20.	Reciprocating performance system-Rechip BETA & Windrock analyzer
21	Power Quality Electromagnetic fields
22.	Shaft magnetism
23.	Dissolved Gas Analysis
24.	Passive Ultrasonic inspection
25.	Radiographic testing
26.	POSMON Ford's system
27.	Sound Analysis Air Testing
28.	Laser guided precision alignment
29.	Offline motor insulation testing
30.	Reciprocating machines Analyzer
31.	IRIS (Internal Rotary Inspection System) tube testing http://www.laser-ndt.com/tubemap.html
32.	Remote Field Testing(RFT) http://www.ndt-ed.org/EducationResources/CommunityCollege/Other%20Methods/RFT/RFT_index.htm
33.	Eddy Current Crack detection & Gear monitoring Techniques
34.	Pulsed Eddy Current and Long Range UT (Ultrasonic)
35.	Magnetic Flux Leakage(MFL)

36.	Motor Circuit Testing
37.	Neural Networks (Diagnostics & prognostics)
38.	Intelligent signal processing(Diagnostics & prognostics)
39.	Qualitative Simulations(Diagnostics & prognostics)
40.	Fuzzy Data Fusion Techniques(Fault diagnosis)
41.	Regression Analysis(statistical Methods for diagnostics & prognostics)
42.	Cluster Analysis(statistical Methods for diagnostics & prognostics)
43.	Bayesian Inference
44.	Dempster Shaffer theory(prognosis) http://www.le.ac.uk/engineering/mjp9/parikh1.pdf
45.	Kalman Filters(Numerical methods for prognostics)
46.	Beacon-based Exception Analysis for Multimissions (BEAM) http://tmo.jpl.nasa.gov/progress_report/42-144/144A.pdf
47.	Dial indicator and laser alignment
48.	University of Cranfield's Pythia (Turbine performance)
50.	IR spot meter
51.	SPM, Smart methods per IDCON's CMS, Laser deviation alignment
52.	Resonant Inspection(RI) http://www.ndt.net/article/hands2/hands2.htm
53.	UltraTEV detectors-for Partial discharge activity http://www.eatechnology.com/
54.	Electrostatic monitoring (ES) -for gas path of jet engines & turbines.
55.	Digital Radiography Inspection
56.	Closed circuit TV(CCTV)
57.	Bispectral Change Detection(BCD)-for reciprocating machines
58.	Antenna based Condition monitoring technique- for AC\DC motors
59.	Curvilinear Component Analysis (CCA) method. http://www.ligo.caltech.edu/docs/G/G030634-00.pdf
60.	Bicoherence method http://www.ndt.net/article/insight/papers/insi.50.3.133.pdf
61.	Motor Condition Monitor(MCM) http://www.maintenanceworld.com/Articles/ibrahim/process-monitoring-maintenance.htm
62.	PiezoDiagnostic technology(PD) http://www.twi.co.uk/content/spsmwoct07.html
63.	Electromagnetic Partial Discharge Sensing

The highlighted condition monitoring technologies and techniques above are suitable for Integrated Operations. It is thus noteworthy that majority of the recent monitoring equipment and techniques have suitable IO characteristics no matter how vague the product might seem suitable for IO. From the use of advanced wireless vibration equipment and techniques to the use of human senses where offshore operator carrying thermography equipment or portable infra red cameras could also transmit the signals onshore for real time visual observations. Therefore it is possible to integrate two or more monitoring technologies together to achieve e-maintenance. Other technologies are enablers for example the LED which is gradually replacing the strobe light. Its compact size has enabled the development of new text, video displays and sensors while its high switching rates are also useful in communications technology.Equipment like the Boroscope or Borescope is now modified with the aid of wireless technology such that one cannot only inspect without cables but can also send the images to a larger screen far away.

Technologies such as the BEACON, Artificial Neural Networks (ANN), statistical or numerical techniques and other prognostics and diagnostics technologies are most suitable because of their autonomous capabilities and are mostly developed as models or software. Equipments such as the CCTV are also suitable for remote monitoring and e-collaboration and can also record events and trigger alarms in the process. The UltraTev detector acts as a perfect substitute for partial discharge activity for Medium Voltage (MV) assets where human senses were initially used to detect any visible, audible change in deteriorating assets which was initially detected with a collection of devices such as thermographic camera, ultrasonic and earth monitor.

It is also quite observable that a major proportion of these equipment and technologies are mainly used for monitoring smaller or auxiliary equipment such as pipes, motors, boilers, gearboxes, gun tubes etc which are numerous and basic plant equipment rather than heavy equipment and could indicate that the smaller vendors are exploiting the non-critical markets by developing patients or technologies towards non-critical equipment thereby leaving the big players to critical equipment market development, an intrinsic market strategy used by the smaller vendors for their sustenance and survival. The ANN however provides the best technology for IO such that in the event of introducing new technologies it is able to identify possible latent parameters that could assists in analyzing machinery degradation to enable fault diagnosis and prognosis.

CHAPTER FOUR
TRENDS IN CONDITION MONITORING EQUIPMENT AND TECHNOLOGY

4.0 TECHNOLOGY TRENDS

Analysis of the current condition monitoring equipments and trends can be viewed both from a service and product or technology segment of the market. The recent trends have been observed and can be summarized in the five major categories below:

- Outsourcing of non-core or maintenance operations.
- Advancement in technology-condition monitoring equipments and other enhancing technologies.
- Shift to a more advanced condition based maintenance (CBM) technology\E-maintenance-e-operations.
- Emergence and high demand of wireless technology i.e. wireless monitoring
- Automation of maintenance functions-Integration of condition monitoring data with plant management systems.

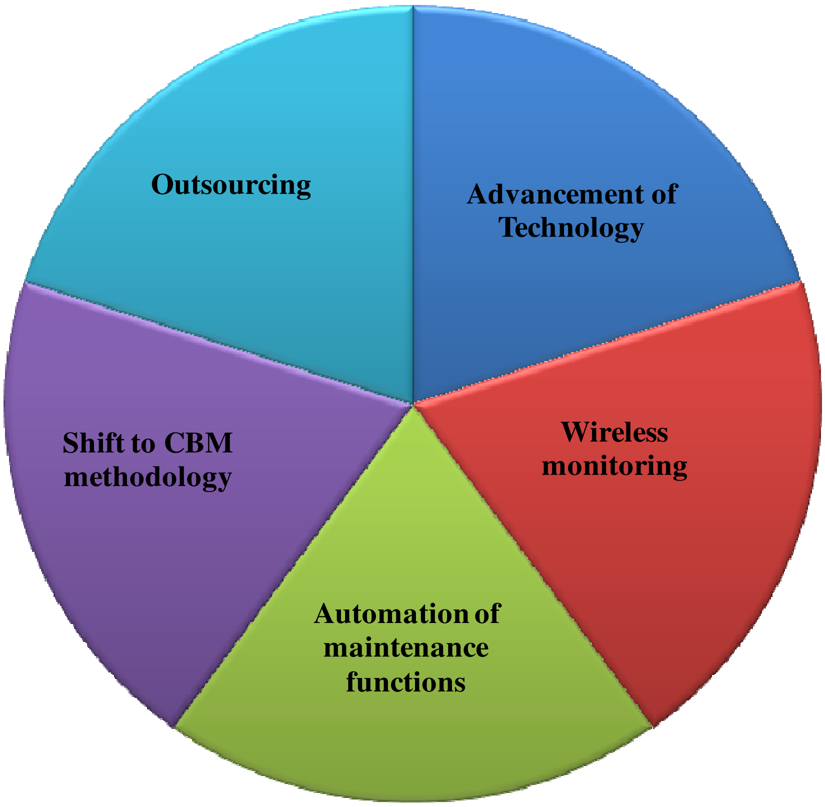


Fig.12.0: Trends in condition monitoring technology

Advancement in technology and use of wireless technology has led to the emergence of this new concept known as Integrated Operation which has now become the main cynosure of the present industrial environment. A concept which is now in adoption but

still under restructuring thus the overall technology trend can also be viewed from an integrated perspective. An integration process which can be observed from three phases, human, technology and organization i.e. human in terms of integrating different disciplines from monitoring experts, monitoring equipment suppliers, logistics, technicians through support centers ,technology in terms of integrating condition monitoring technologies with other plant management systems such as process control systems, CMMS e.tc to be guided by integrated standards and organization in terms of organizational restructuring to accommodate the various roles that will be assigned to the integrated team of experts.
It can be illustrated with the use of a triangle below where integrated operations form the locus of the three H-T-O phases interacting as a result of the integration and collaboration between teams consisting of end-users of CM equipments, suppliers, CM and logistics experts from different businesses of by with the aid of innovative technologies and ICT systems to improve and hasten maintenance operations and decisions respectively. Although this concept has been in existence with different names by the respective companies but is now restructured under a common umbrella known as Integrated Operation.

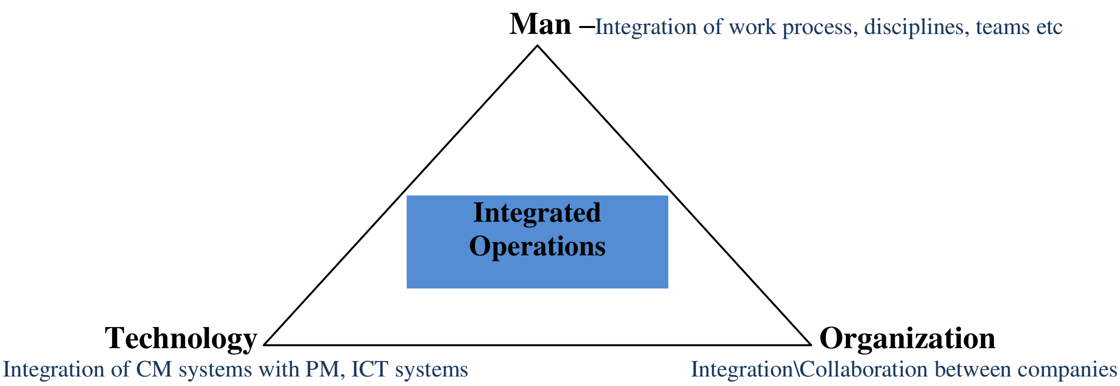


Fig. 13.0: IO-the locus of H-T-O phases.

4.0.1 OUTSOURCING-PRODUCTS AND CONSULTING SERVICES

Managing a variety of business functions in the oil and gas industry such as marketing, operation and maintenance, refining, drilling and seismic operations etc has become complicated and expensive. Even with the current mergers, acquisitions and consolidation, most operators are still trying to find balance between the rising global energy demand and the diminishing energy resources. This has made them susceptible to competitive pressures especially with the emergence of the Asian tigers as they try to optimize cost without jeopardizing safety and quality. Furthermore, according to the Cambridge Energy Research Associates (CERA), the average age of skilled personnel or engineers in the oil and gas industry is 51 with a possibility of 50% retiring by 2015 which consequently will lead to labor shortage and personnel loss either through retirement or as a result of downsizing as currently been experienced in the oil and gas industry due to the global financial crisis. Business process outsourcing is now the ideal strategy been adopted by operators to address such challenges.

In the service market segment operators are now focused on their core activities and are outsourcing the non-core activities to specialized service companies capable of offering cost effective condition monitoring and asset management services. It is the emergence of a business to business service (B2B) which simply involves buying the service or function of the condition monitoring equipment rather than the product thus giving these specialized companies control over their risk management services and around the clock monitoring activities. The current conditioning monitoring consulting and services market consists mainly of vibration condition monitoring, thermography and lubricating oil analysis.

Sandy Dunn (2008) in her article on condition monitoring in the 21st century accentuated that the current business need of most operators is to maximize profits from minimum investments in their plant and equipments, a term she defined as ‘asset effectiveness’ which could be achieved if these condition monitoring vendors are able to meet the demands of its clients by:

- Improving equipment reliability which can be attained through the use of efficient monitoring services and technologies able to predict and prevent equipment failures so as to avert environmental and safety hazards which is now been prioritized in the oil and gas industry.
- Minimizing downtime through integrated planning and scheduling of repairs which are dictated by condition monitoring techniques.
- Maximizing component life by avoiding the conditions that reduce equipment life (for example, by ensuring ongoing precision alignment, minimal lubricant contamination etc.)
- Utilizing condition monitoring techniques to improve and maximize equipment performance and throughput
- Reducing condition monitoring costs to an acceptable level.

The above demands are now been looked into by most vendors i.e. from the development of highly reliable systems or components to the use of integrated planning which is a means towards achieving integrated operations. Therefore the service segment of the market still has possibilities for future growth when compared to the product segment and with the emergence of Integrated Operation, the service segment will continue to generate more room for opportunities and expansion.

4.0.2 ADVANCEMENT IN TECHNOLOGY

New technology in the 21st century has produced a significant impact in the condition monitoring market. From the emergence of advanced technology and Information and Communication Technology (ICT) whereby condition monitoring equipments can be automated for remote monitoring operations of facilities and accessed irrespective of distance or location using internet and networking technology, a key driver towards Integrated Operations. More flexible products and powerful software with a variety of maintenance capabilities are now available and the use of mathematical models, numerical methods and artificial intelligence (expert systems) techniques for fault detection (diagnostics) and prognostics are new cutting edge technologies that are evident in today's industries. This advancement in technology has led to less reliance on skilled labor, a more accurate and highly reliable condition monitoring equipment and a subsequent shift to a more advanced condition based maintenance technology. To also achieve the reliability demands and the internal and external challenges of its clients, there has been rapid advancement in the product and technology segment of the condition monitoring market. For example Reliability Centered Maintenance (RCM) was the ideal predictive maintenance (PdM) choice to cut down monitoring costs and avoid unnecessary preventive maintenance activities. The methodology provides the basis for the frequency of condition monitoring tasks through the lead time to failure or the PF interval(potential warning time against a functional equipment failure) and further attempt to improve the accuracy of PF Interval estimation for condition monitoring technologies have in the past been a challenge because estimates of this interval are not available on reliability data but were made based on expert judgments or by deteriorating mechanism and equipment specialists (Rausand and Høyland, 2004).However, with advanced software such as EXAKT that will be discussed later such a challenge have been solved.

Other advances that have enhanced condition monitoring technologies include the use of wireless sensor networks such WiMax, Wi-Fi, Ethernet and advanced robotic technologies.

4.0.3 SHIFT TO AN ADVANCED CONDITION BASED MAINTENANCE (CBM) METHODOLOGY-E-MAINTENANCE

The acceptance of condition based maintenance technique or monitoring within the mainstream of operations and maintenance by most end-users and service providers has been stimulated further by technological advancements and commercial demands for improvements such as quality, productivity, inventory control, plant and machinery expenditure (Phillip et al, 2004). The choice of predictive maintenance (PdM) task along with condition monitoring to determine or schedule corrective or preventive maintenance tasks emphasized by the Equipment Specific Maintenance Procedures (ESMP) in the BP\VRD maintenance strategy is a perfect example of the rapid acceptance in condition based maintenance in the present industries. More so, technological advancements such as the wireless technology, ICT, monitoring equipment and supporting monitoring software which can store and analyze results has also promoted the rapid adoption of this technique amongst operators and vendors alike.

In recent times, there has been a shift from the traditional CBM practice which was more of offline or serial communication such that the expert has to be present within the physical asset environment to monitor and collect data or use the local area networks(LAN) to establish communication between the expert and the physical asset. The recent methodology now establishes a point-to-point communication between the expert and the asset irrespective of location with the use of wide area networks (WAN) and web-based services to not only communicate between the expert and the asset but within various technical experts from the CM vendor, original equipment manufacturer(OEM),maintenance contractor, the plant operator, spare parts and logistics personnel, the mobile expert, planning engineers etc (Liyanage et al, 2009).This conventional method was made possible with the emergence of integrated operations. The framework or workability of this concept is dependent on three key areas:

- **The application technology:** dealing with the monitoring equipments and other technologies for data acquisition, analysis(sensor technologies, diagnostic and prognostic equipments etc),communication between experts from different locations either onshore or offshore with the use of WAN or use of RFI D's or GPS to connect mobile physical assets like drilling ships, FPSOs, cargo vessels etc,

- **The business to business organizational structure:** These technologies will have to be supplied, manned, operated and maintained by various business units collaborating together to make it function. Units consisting of suppliers of monitoring and telecommunication equipments, logistics experts, maintenance experts etc thus establishing a form of business to business partnership which would require a common support structure where e-maintenance solutions can be sourced.

- **Work performance:** With the various business units and technical partners assigned with roles and responsibilities within the support structure.

New technologies such as the neural networks, artificial algorithms, fuzzy logic and Dempster Shafer theory has immensely improved the performance of CBM systems such that these systems are able to not only diagnose an equipment condition but also prognose its remaining life before final failure. (Vachtsevanos and Wang, 2001).These are known as Intelligent CBM since they are capable of making independent decisions without human assistance and can be further grouped into localized and remote CBM's depending on their deployment. With the latter a part of e-maintenance or it can also be termed internet CBM. Localized CBM occurs within the vicinity of the physical asset which is being measured by the maintenance expert. (Philip et al, 2006).

In terms of monitoring equipments, we now have smart sensors with built in intelligence and other sophisticated monitoring equipment. There is now a high industrial demand for flexible, powerful and portable equipment and user friendly software which has enabled easy, reliable and rapid data transfer across locations and integration with larger process control systems and databases.

In summary, according to Phillip et al (ASME, 2004), recent technological breakthroughs now include:

- Improved knowledge of material failure mechanisms
- Advancements in failure forecasting techniques
- Advancements in low cost monitoring systems and sensor devices e.g. smart sensors some of which are now built in as standard feature in large equipments such as motors, turbines, pumps etc.

- Advancements in ‘expert’ diagnostic and prognostic condition monitoring software.
- Acceptance of standard communication protocols
- Developments in maintenance software application and networking technologies.

4.0.4 DEMAND FOR WIRELESS TECHNOLOGY

It is a mobile and collaborative technology (MCT) that is integrated into plant system and its recent demand is been driven not only by low cost but its portability, accessibility or system flexibility, localization, reachability and identification. (Krotov, 2006). Wireless technology has revolutionized condition monitoring both in terms of demand for wireless condition monitoring products to wireless sensor networks(WSN).From cost benefit analysis (CBA) against wired systems, wireless technology is now the ideal solution for reducing costs in terms of installation, labor cost, energy savings, maintenance and operating cost and has been the pioneer of remote monitoring activities and e-maintenance operations\integrated operations in the oil and gas industries today. Cost analysis undertaken by one of the operators on the Norwegian continental shelf (NCS) found that wiring online systems could cost about 144,000 kroner per point which is very expensive. Wireless online system increases productivity such that it is able to provide information and data wherever needed irrespective of time, geographical location and the quantity of required data or information which is often voluminous for O & M activities. These data could consists of process control data, failure history, diagnostic data, manufacturer’s guidelines, work orders and scheduling, condition monitoring data etc.

The architecture could consist of monitoring equipments such as sensors, specialized embedded system units for equipment data collection, personal digital assistants(PDAs),laptops, smart phones and tablets; each with its individual set of characteristics that is most suitable for condition monitoring applications, data collection, transfer etc. Therefore most monitoring vendors are embedding wireless technology into its products for example SINTEF Micro and Nanotechnology Laboratory adopting silicon technology used to produce integrated circuits has recently produced a small autonomous sensor unit which is mounted on motors. It consists of a vibration sensor, temperature sensor, a battery driven microcontroller with a circuit for wireless communication linked to a central computer which analyzes data and converts it into useful information for the users or experts. More so, wired sensors like vibration sensors have been known to alter slightly frequency domain charts which wireless system avoids.

The current trends in the use of these mobile technologies have been summarized below:

TRENDS	3G DERIVATIVES	WI-FI	WIMax
Standard	HSDPA\HSUPA,EV-DO	802.11x	802.16x
Maximum bandwidth (lower effective bandwidth in practice)	14.4 Mbps(HSDPA), 5.8Mbps(HSUPA), 46.5Mbps(EV-DO Rev.B using all carriers)	11 Mbps(b), 54Mbs(g), Over100Mbps(n)	Over 70 Mbps(fixed) 15 Mbps(mobile)
Operations	Cellular operators	Individuals, Wireless Internet Service Providers(WISPs)	Individuals, Wireless Internet Service Providers(WISPs),wireless operators
License	Yes	Yes	Optional
Optional	Optional	Optional	Optional
Pros	Range, mobility	Bandwidth, costs	Bandwidth, range, mobility
Cons	Price	Short range, Poor Quality of Service(QoS)	Interference issues in unlicensed bands

Table 3.0: Characteristics of trends in mobile technologies (Tan 2006).

Wireless technology consists of various types or protocols with each protocol having unique features and market advantages than the others. These protocols are: Wi-Fi (802.11x), WiMax(802.16),the emerging MobileFi (802.20x),post-3g protocols, Wireless Personal Area Networks(WPAN) and RFID technology.(wheeler, 2007).(Chawla and Ha, 2007).The family of the wireless protocols exhibits certain strength and distinctive characteristics and thus market trends in these protocols depend on their respective cost, quality of service and interference. (Liyanage et al, 2009).The strengths of the individual protocols can be summarized below:

- **Wi-Fi:** This family of protocol also known as 802.11b\g is generally accepted and popular worldwide amongst monitoring vendors thus occupies a major part of the market. It is the same technology used for laptop computers and office wireless LAN. Its technical capabilities in terms of bandwidth which is high and other advantages which include network security, moderate energy consumption (1-2years), and comprehensible standard implementation has made this technology ideal for condition monitoring operations.(Bondoc, 2009). It operates in the unlicensed spectrum of 2.4GHz and 5 GHz bands and is now seen as a complementary protocol with other service providers rather than competitive(Liyanage et al, 2009)

Limitations: it exhibits short range of coverage of about an order of tens of meters thus problems exists as interoperability problems have to be addressed when trying to extend the range via mesh topologies and furthermore there is lack of support for quality of service(QoS) in multi-media rich transmissions.

- **World Interoperability for Microwave Access (WiMax):** This is a relatively new technology with several vendors developing the support infrastructure. Companies are now scrambling to be the first to be the main providers and thus define the standard to which others must conform. Firms like Intel and Fujitsu are now among the leading providers of WiMax compliant SoC chips which can be used to make Customer Premise Equipment (CPE) that are used to access WBA base stations. This has been in use since 2005.WiMax exhibits wide area coverage in kilometers with a far better QoS when compared to the Wi-Fi thus allowing multimedia rich transmissions with quality guarantees. It is designed to operate both in license and unlicensed frequency bands with very probability of taking over the Wi-Fi market penetration in the near future.

The WiMax technology is affordable with an ability to bring high speed internet and low cost broadband wireless roaming solution to low speed internet and high speed internet businesses respectively. Compared to Wi-Fi it operates at a higher speed, covers longer distances and has a wide user capacity.

Limitations: Contrary to the perception that the range varies with the speed rate i.e. 70bits over 50kilometers, its speedrate is inversely proportional to its range. At higher range of over 50km requires a lower bitrate while lowering the range allows the device to operate at a higher bitrate of which in the event of a lower bitrate, an increase in the bit error rate is expected.Wi-Fi develops wireless LAN to access high speed internet or access just a network for file sharing while WiMax is a latest technology for not only high speed internet but for data, voice, video transfer at higher rates which is ideal for e-maintenance. Wi-Fi on the other hand is easily deployed much more than WiMax because of its ease of installation and cost effectiveness.

- **Radio Frequency Identification RFID technology**: RFID on the other hand offers many advantages in today's modern maintenance and asset management technology. It is used for identification through RF readers and its ability to store history data readings and enable structured and decentralized data storage (Legner and Thiesse, 2006).Furthermore it enables computerized tracking and handling of assets and integration of maintenance and asset management with Enterprise Resource Planning (ERP) and the overall operation and maintenance activities of the enterprise. However RFID technology can be hindered by certain challenges which could be financial or technical challenges. Technical challenges in terms of hindrance by metal surfaces or liquids therefore the need for reliable operations in diverse operating environment and financial challenges in terms of infrastructural development to support the RFID tracking. (Wu et al, 2006)

- **For 3G technologies**: The CDMA 2000 has been the leader in 3G technology worldwide with expectation that by 2009, more than 60% of CDMA 2000 operators will offer mobile broadband services based on Evolution-Data Only (EV-DO). It now accounts for about 64% of the 3G market worldwide thus able to offer much consumer choices at lower cost to vendors. (CDMA development Group, 2009).

4.0.5 AUTOMATION OF MAINTENANCE FUNCTIONS-INTEGRATION OF PLANT ASSET MANAGEMENT SYSTEMS (PAM)

The business need to have a holistic view of the total plant condition and the need to attain high accuracy in failure prediction so as to eliminate unscheduled maintenance repairs has led to the integration of computerized maintenance management systems(CMMS) with predictive maintenance technologies(PdM) and process control systems. Previously experts linked these two systems by inputting PdM data manually into the CMMS which was time–consuming considering the need for real time accessibility of information. However these challenges have now been overcome by automatically integrating the CMMS (consists of preventive maintenance (PM) scheduling, inventory control, work orders, safety and asset management data etc) predictive maintenance system (comprising of CM data and trend tracking analysis from vibration analysis, thermography, lubricating oil analysis etc) and process control data. With this integrated approach, industrial end-users are able to implement different monitoring strategies such as continuous monitoring, online surveillance, and use of portable monitoring instruments etc which are based on safety, the equipment's criticality and failure modes. The effectiveness of this automation has led to low risk of unscheduled downtime since impending machine failures are been detected early and thus is also a cost effective approach such that maintenance resources are efficiently utilized.

Workability of this integration process calls for the development, acceptance and implementation of standard protocols. These protocols are now been developed and currently the best CMMS databases feature open architecture such as ISAM (External Indexed Sequential Access Method using MS Access, Dbase, FoxPro, Btrieve, Paradox etc) or ODBC (Open Database Connectivity using Microsoft SQL Server, Sybase SQL, Oracle etc). The essence of such open architecture is to enable the CMMS databases to be read from and written to by PdM programs with ISAM and ODBC capabilities (Lofall and Mereckis, 2001). Other common industry-standard protocols needed to interface these systems with one another include the Object Linking and Embedding for Process Control (OLEPC) been supported by Predict-DLI integrates process control data and condition monitoring data. These protocols apart from readability access are also adopted to further reduce the cost of ownership. (Dunn, 2007).Most condition monitoring suppliers such as CSI, Rockwell automation now offer integrated condition monitoring software which effectively integrates condition monitoring technology data into reports

and also an increasing number of CMMS vendors now incorporate condition monitoring modules to specified CM packages within their software.
(Walejeski and Kalanik, 2002).***Figure 14*** below gives a perfect description of the integrated condition monitoring and assessment system been utilized in the industry today.

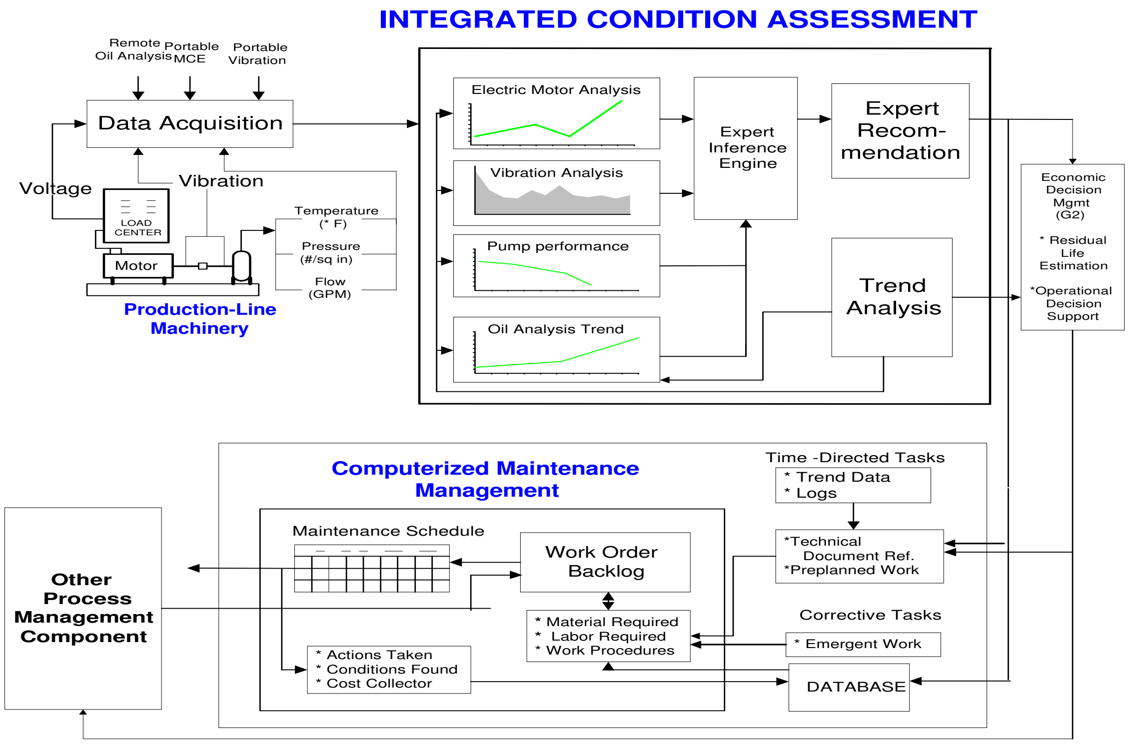


Fig. 14.0 Integrated Condition Monitoring and Assessment system (Staller, ICM Technologies Inc.)

This is major step towards reducing information and communication complexities that could hinder e-operational objectives and is definitely a step in the right direction.

4.1 THE FUTURE OF CONDITION MONITORING

The enactment of strict safety and environmental laws by authorities has enhanced the high demand for reliable equipments by end-users and will lead to widespread acceptance and continuous use of condition monitoring equipments not only for predicting equipment failure but for improving equipment reliability and performance. With the world been a global village as a result of globalization and accompanying industrial mergers and acquisitions, industrial plants are now connected to a more global network, the future of condition monitoring now depends on development in enabling technologies such as ICT capable of not only enhancing condition monitoring technology and its applications but providing a resource point through which valuable information, data (historical, condition monitoring, preventive maintenance etc),expertise and

competences can be sourced from to address reliability and other O &M issues of industrial plants irrespective of location.
Advancement in sensor technologies has seen the emergence of highly reliable, efficient and smart sensors some of which are now embedded together with the equipment and also the introduction of 'smart' software packages capable of carrying out multiple analysis capabilities and the development of artificial intelligence algorithms capable of making autonomous decisions e.g. the fuzzy logic, the expert rules, neural networks etc These are expected to be the future key monitoring technologies towards achieving desired O & M objectives. The emergence of wireless technology is now seen as the gateway towards unlocking the future of condition monitoring technologies where data and information can be accessed from anywhere around the world. This IO-enabler is currently been implemented in the oil and gas industry and has the potential of spreading to other industries. Accessibility to data has been a major challenge in the past and it enables experts in making timely maintenance decisions in order to optimize their assets for maximum productivity and profitability.

The future of condition monitoring as described with the tree structure below lies with having a global service or support center linked with the aid of enabling technology such as fiber-optics to other individual service centers either offshore or onshore with access to its industrial plant and facilities such that data from these sites can be accessed from this single center. The bigger picture lies in the integration across companies where both the industries, condition monitoring vendors and experts can have access to the same information at the same time irrespective of the location. But for there to be sustainability the future of integrated operations would still depend on developing a common technical language or widely accepted open standards and standardized protocols which would need the collaboration of various international standard organizations and acceptance of the manufacturing industries, the latter a major challenge to overcome.

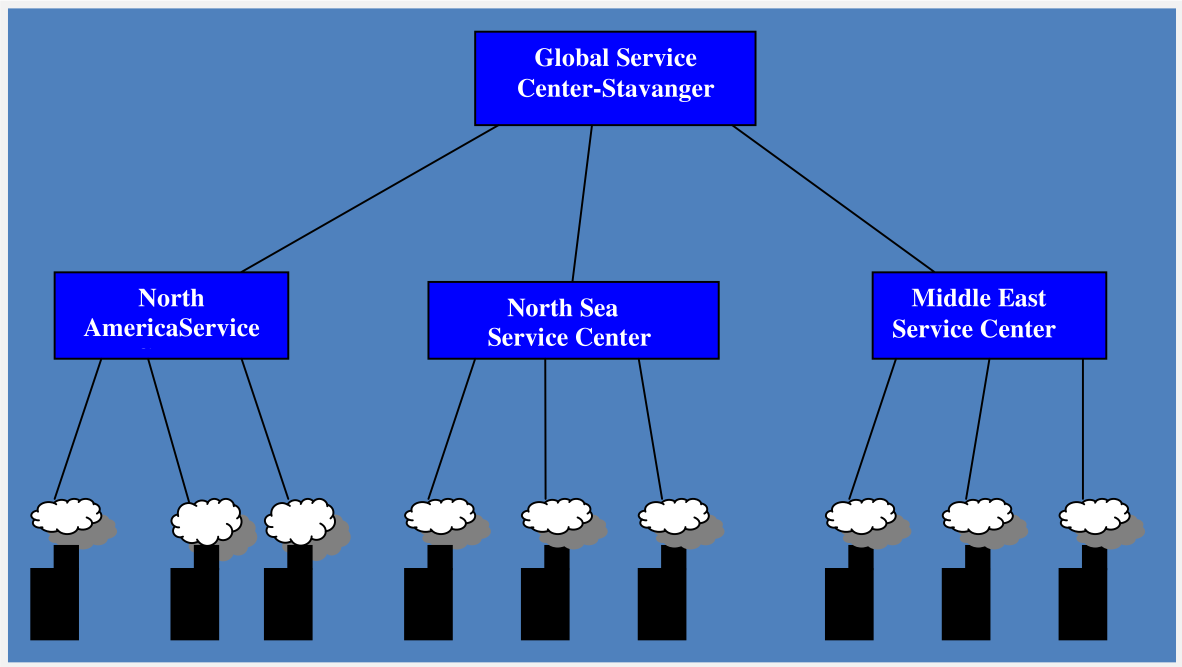


Figure 15.0: A tree structure of integrated condition monitoring operation\e-CM (Nikunen et al, 2000)

4.2 POSSIBLE CHALLENGES AND IMPLICATIONS OF THESE TRENDS TO END-USERS, VENDORS AND MARKET.

The recent trends in condition monitoring technologies are still experiencing some challenges which still have to be addressed even as funds and research are currently being expended to address these challenges.

4.2.1 CHALLENGES OF OUTSOURCING

Outsourcing condition monitoring services provides the ideal platform for operators and end-users to focus and improve their core activities while saving cost. The general acceptance and increasing use of condition monitoring technologies coupled with the shift in know-how from experts to mere technician has led to proliferations of CM vendors or contractors in the market with everyone claiming to be a consultant. This poses a serious business risk and the need for these independent CM to be audited and inspected according to standard industry practices. For equipment and service suppliers they must show evidence of backup instrumentation for their equipment which must conform to the appropriate industrial standards. Other possible risks could evolve such as contract termination between the two parties whereby data collection though done internally by the contractor is submitted externally in hardcopies with the contractor in possession of the raw data. This calls for the need for retain any computerized data by providing the condition monitoring software which will enable them observe trends at anytime, provide data at the request of another contractor, and dictate standards and measurement quality(Hills,2006).Outsourcing also will definitely accelerate the decline of in-house skills for the clients coupled with the fact that majority of the in-house engineers are gearing towards retirement age with most of the engineers as old as the same plants they built themselves thus rather than having a knowledge transfer to new recruits through training programs, the clients are outsourcing their operation and maintenance services while reducing in-house recruitment. There is now an increasing focus by the contractors on the client's business need and challenges with thorough research into possible ways of creating and adding values to these needs and curbing these challenges.

4.2.2 CHALLENGES IN TECHNOLOGICAL ADVANCEMENT

For smaller condition monitoring companies with less funds into Research and Development(R & D) they would not be able to compete with the big players in the industry and in the process are liable to liquidate if trying to keep up or probably end up been bought over by the big players, a trend currently been experienced in the condition monitoring industry today. Furthermore there will be a rapid decline in the reliance of skilled labor because of the various automation and instrumentation systems been used in the industries and is likely to affect the job market in years to come

4.2.3 CHALLENGES IN UTILIZING ADVANCED CBM TECHNIQUES\E-CM

The adoption of advanced CBM techniques which is the subject matter of this thesis is likely to be faced with daunting challenges. Challenges include security and reliability concerns over internet transactions and competing interest of vendors i.e. reluctant to adopt open standards by encouraging monopoly through their propriety standards. Also the stress associated with change management likely to be experienced by both the experts and operators due to reasons such as organizational restructuring, new roles and responsibilities expected to be undertaken by the various parties, intensive training and competency development to keep up with the information flow and advancement in both e-collaborative technologies and telemaintenance principles.

Worse still, internationally accepted qualifications to ISO 18436 which is a recommended standard for condition monitoring and diagnostics of machines is just newly gaining acceptance in USA, Europe and Asia pacific (Hills, 2006).It also cannot be viewed as a stand-alone maintenance technique therefore to ensure its full benefits must be integrated with preventive maintenance or other techniques to obtain a holistic view of machinery health and performance.

4.2.4 CHALLENGES OF WIRELESS VIBRATION MONITORING EQUIPMENTS AND NETWORKS

There is a decreasing use of handheld vibration sensors since the emergence of wireless sensors. Due to the large amount of data that is required to be sent over the wireless link, a variety of requirements are needed. Requirements must include high bandwidth and level of processing capabilities, good dynamic range, low noise levels, and effective data capturing capabilities that saves time. For wireless sensor networks (WSN) in use in offshore platforms there is disruption in data exchange due to the presence of extensive steel structures and other typical offshore structures such as large power generators, UHF/VHF radios, radars, safety and automation systems, WLAN etc the latter which is the most used technology in the industry, therefore companies supplying such wireless technologies e.g. ABB are thus seeking suitable standards to enable both WSN and the WLAN to co-exist to avoid such disruptions(Birkemoe, 2008).Furthermore there are challenges such as environmental challenges where these technologies are yet to be tested e.g. Goliat project in the arctic region and other difficult terrains, in-house challenges been faced within the normal industrial environment which could be water exposure, extreme temperatures, electrical interference, hazardous-area classifications etc and finally the power source required to energize these devices.

4.2.5 CHALLENGES OF INTEGRATING PLANT MANAGEMENT SYSTEMS

The market for the process control software and hardware is larger than that in the condition monitoring markets and has spurned the acquisitions of existing CM equipment vendors by their process control equipment counterparts. Such acquisitions earlier led to loss of competent personnel from most of the original suppliers. Examples can be seen from Rockwell automation that acquired the merged Entek-IRD, Emerson acquisition of the CSI of USA, the last independent player, Bently Nevada was bought by General Electric with just few left in the core monitoring markets e.g. company like the Bruel & Kjaer and Schenck which was able to fight off market forces with new innovative vibration data collection products. This changes really slowed the development of condition monitoring techniques in recent times due to the fact that these big players for example Bentley Nevada are more focused on integrated plant management systems than the core condition monitoring technologies.SKF and Rockwell for example source instruments from the same supplier with no instrument development competence of its own. The fallout from such scenarios has led to high demand for experts or experienced personnel in condition monitoring technology with most of these engineers seeking for greener pastures in the Middle East since their skills are unique. Most companies now investing in training of CM staff so as to implement this technique within its facilities in order to curb the skill shortages but are faced with daunting challenges in the process both in the training and maintaining such personnel.

Other challenges include establishing and accepting a common data exchange network through which plant management systems can be exchanged between different users which will be a key toward unlocking condition monitoring-IO potentials.

CHAPTER FIVE
SUITABILITY OF TODAY AND FUTURE MONITORING TECHNOLOGY FOR INTEGRATED OPERATION

5.0 KEY MONITORING CRITERIA FOR INTEGRATED OPERATION.

Suitability of the present condition monitoring (CM) equipment and technology for integrated operation lies in its ability to monitor equipment and analyze data virtually in real time to be able to provide useful information. One must take into cognizance that the basis for the selection of any condition monitoring and performance monitoring tool must be its data accessibility independent of location therefore such tools are the true IO enablers. However in recent times these monitoring equipment or technology have not only diagnostic but prognostic capabilities enabling fast and on-time decisions and also possess remote monitoring capabilities. Other capabilities include handling large amount of data ranging from process control data, historical data, preventive maintenance data, etc and monitoring multiple plant conditions for example new CM equipment such as sensors can monitor other parameters other than vibration e.g. parameters like pressure, temperature, etc.

Therefore the following salient e-maintenance characteristics or criteria are currently evident in today's monitoring equipment and system and must be taken into consideration for an integrated condition monitoring project.

They are capable of:

- Monitoring, acquiring and analyzing data in real time eliminating the human element coupled with other prognostic, diagnostic and autonomous decision making capabilities.
- Providing remote access to these data and information independent of location to the various stakeholders.
- Furthermore, an enabling communication infrastructure & open standards or communication protocol for system interface capacity.
- Increasing levels of Integration to reduce complexities and increase efficiency.

Condition monitoring technologies like the artificial neural networks, the fuzzy data fusion techniques etc are most suitable towards achieving autonomy and support of maintenance decisions which are requisite criteria towards implementing e-operations.

5.1 PROGNOSTIC AND DIAGNOSTIC CAPABILITIES

These are key features in today's monitoring equipment from innovative sensors to online monitoring systems. Prior to the advent of prognostic characteristics, monitoring equipment had the capability of simply monitoring equipment conditions and acquiring data after which the resulting data is sent to the maintenance experts to convert to useful information for further analysis. But latest condition monitoring equipment have diagnostic and prognostic qualities which are capable of detecting failures and predicting failure possibilities and equipment health with no expert intervention as soon as the measured data is received. This saves time and has been made possible with the support

of analytical software with embedded mathematical models or qualitative methods such as fuzzy logic, neural networks and other artificial intelligence methods for the decision making process. Therefore the integrated operation concept is about saving time thus such prognosis of an imminent fault or failure would lead to the Onshore O &M crew issuing the necessary work orders for maintenance actions.
Current prognostic approaches can be classified into data-driven approach, model-based and a combination of the two known as the hybrid approach (Ni et al, 2009). The model based approach identifies and evaluates the difference between the measured state of the equipment and expected operating state derived from inherent characteristic value from its physical model while the data driven approach derives behavioral models only from measurement data of the process itself from which qualitative methods can be used to enhance prevention of probable faults (Liyanage et al, 2009).This prognostic information not only assist in enforcing condition based maintenance but also serve to further improve process reliability and product quality as described below.

CASE STUDY: BENTLY NEVADA ONLINE MONITORING SYSTEM

The Bently Nevada system is a product of General Electric (GE) and it currently stands as the most popular condition monitoring system in the oil and gas industry due to its ability to monitor equipment independent of size, location or function therefore a perfect system for monitoring both critical and non-critical equipment and machineries. The system is a continuous monitoring online system having different products ranges. Its suitability is such that it can manage and analyze data from various sensors e.g. vibration sensors connected to different equipments or points. It can be integrated with a data manager (DM) 2000 system software capable of capturing and displaying information or data on the mechanical condition of the an equipment, a Trend master(TM) 2000 which is a data acquisition system monitoring static and essential machines and equipment. Both of which can be connected through digital communications links TM2000 DDE (dynamic data exchange) and PI DDE interfaces to the Distributed Control System (DCS) so that the machinery information is accessible online through the desktop computers to operators. Also critical systems like gas turbines would be recommended to adopt the GE's Bently Nevada* 3500 Series machinery protection systems which provide both protection and monitoring of these equipment such that in the event of any sudden changes during operation mode such as high vibration occurrences, it is able to trip the unit. This has given GE's Bently Nevada systems a competitive advantage over other products in the condition monitoring market. By using standard digital communication interfaces, the Nevada system enables the display, annunciation and trending of data.

GE offers the system1*software which can be integrated with the Bently Nevada online monitoring system. The software helps to process and store all the monitored data, both static and dynamic data while at the same time it is able to offer diagnostic and prognostic assistance to the operators and experts. The system1*software database is receptive to data from an external system thus allows correlation of both process, operating and condition monitoring data for diagnosis and prognosis. Prognostics such that it can report the future health and performance status of the asset and also or estimate the remaining useful lifespan of the asset and diagnosis such that it can project the asset fault condition. The IO-suitability of this product is such that it supports remote client\server connectivity such that various users are able to connect to the system1*server for different purposes ranging from real-time data collection for future comparison with historical data, remote diagnostics and optimization etc.

The application of the Bently Nevada systems or products is seen not only beneficial to monitoring critical machineries like turbine, compressors etc but is also suitable for other essential and auxiliary assets that make up the plant, assets such as motors, pumps, heat exchangers, fans, pipes, blowers etc. Sensors used to monitor the vibration parameter of pumps, motors can be linked to the Trendmaster 2000(TM 2000) which monitors the essential machines. Furthermore the TrendMaster* ProSystem 1* platform provides an on-line leak monitoring and detection solution for process relief valves.

5.2 AUTONOMOUS DECISION-MAKING CAPABILITIES:

Condition monitoring equipments or technologies with such capabilities will be most suitable for the competency development such that it is able to analyze the large volume of monitoring data in less time and make-up for shortages in in-house experienced monitoring experts that has been as a result of outsourcing and thus can be easily understood by maintenance personnel or operators. Software like EXAKT helps to optimize condition based maintenance activities and would be suitable for areas with difficult terrains such as the OLF generation 2 areas in the high North and subsea facilities where constant inspection cannot be guaranteed. It is also a suitable diagnostic and prognostic tool.

CASE STUDY: EXAKT SOFTWARE-THE CBM OPTIMIZER

A recent breakthrough is the emergence of advanced statistical models such as the Markov chain model and Proportional hazard model (PHM) i.e. the EXAKT software which provide an estimated time to failure or a remaining useful life estimate (RULE) of equipment. The EXAKT software is a product of Optimal Maintenance Decisions (OMDEC) Inc in Canada and was said to be developed by a group of engineers, programmers, mathematicians and statisticians at the University of Toronto in Canada. This software not only predicts PF intervals for operators but is useful in making good maintenance decisions such as repair, replace and inspection decisions and as such a suitable IO tool which integrates data with decision making software. It links from the computerized maintenance management system (CMMS) which stores the lifetime or age data (failure data and preventive replacement data) and the historical data (CM data) as illustrated below.

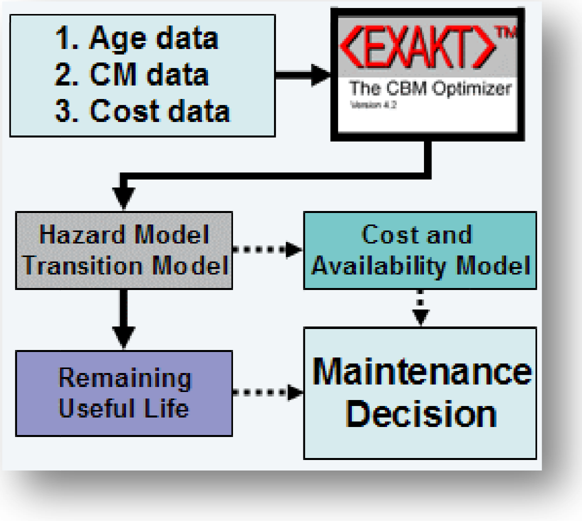


Fig.16.0: Flow diagram of EXAKT (Wiseman et al, 2009)

In operation and maintenance context, reliability is simply achieving a desired production rate, quality, availability, mission survivability at the lowest possible cost without infringement on environmental and safety norms (Wiseman et al, 2009).Maintenance engineers see these as objectives which are always conflicting with one another and so have often been left with no choice but to reach a compromise of which in maintenance terms indicates optimization. For example running a turbine to increase availability would go at the expense of cost. The EXAKT is a unique software package that uses the CM data, age data and cost information to compute the corresponding optimum component replacement strategy and optimize important replacement decisions by selecting the best possible objectives at the minimum cost. The figure below provides an outlook on the efficacy of the EXAKT software.

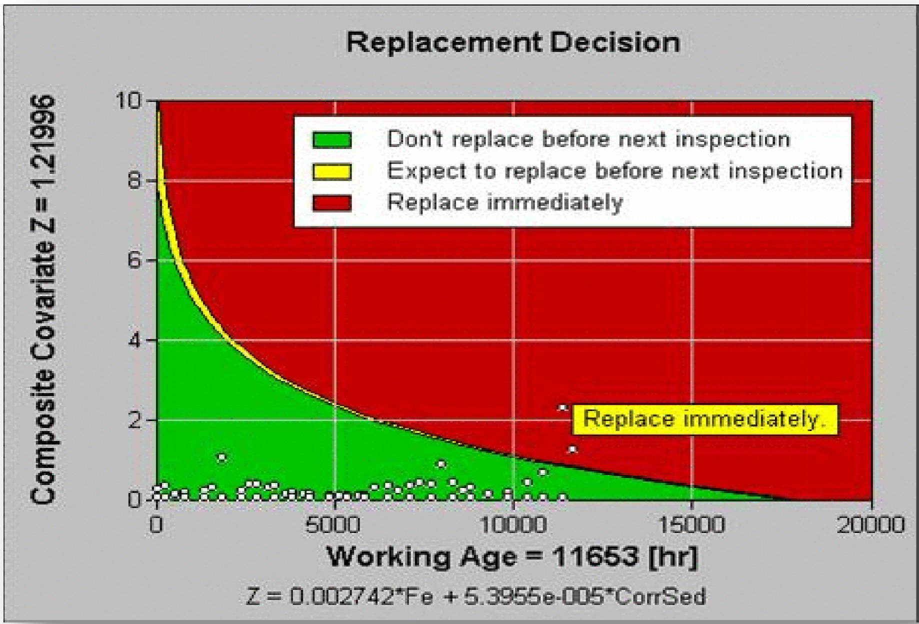


Fig. 16.1: EXAKT Traffic Light Function Screenshot (OMDEC Inc.)

By identifying clear alarm levels on condition of the asset, the maintenance expert is able to get a clear picture of his asset and thus plan when to carry put inspection or when to replace the components. Furthermore**,** it provides the potential risk of any possible failure and also the cost of consequences of any potential asset failure.

5.3 UBIQUITOUS MAINTENANCE CAPABILITIES -REMOTE ACCESS TO DATA INDEPENDENT OF LOCATION:

Condition monitoring equipment and systems are capable of providing an open access to multiple users or all the respective parties involved in the e-operations thereby increasing efficiency from supply of spare parts, making fast decisions and knowledge transfer from experts to operators etc. advancement in mobile and networking technology such as wireless technology and internet technology has enabled the various stakeholders to have easy access to the equipment data in real time.

Advancement in active wireless sensor (AWS) technology has taken into consideration space limitation and size, possibilities for data accessibility independent of location and also the possibility of a 24\7 operation which is now possible because new sensors are now developed to function with low power. An example is the integrated wireless vibration sensor with advanced vibration and thermal process systems developed by the collaboration between ABB, SKF and SINTEF with the use of micro and nanotechnology. It is said to be portable thus smaller than other competitive products with the battery, antenna and circuit board are all housed in a cylindrical-shaped container less than 4 inches tall and less than 1½ inches in diameter thus easier to install or mount on a motor or any equipment and would be most feasible for remote offshore structures where space is limited(Petroleum Economist magazine, 2009).It is able to register abnormal vibration patterns with its accelerometer and temperature which allows for easy data transmission to a centralized onshore computer for analysis and storage for user availability where the data or information can be accessed through WAN by the various stakeholders.

Therefore by embedding RFID tags into these sensors, they can be monitored and tracked from various locations and would be most appropriate for facilities and equipments on mobile offshore units like FPSO's or mobile drill ships. Asset tracking technologies like LBS (location based services used with telematics) can then generate data captured from these remote locations. Mobile technologies are also capable of offering LBS services which can be of benefit for a wide range of applications such as logistics, indoor and outdoor navigation aid and location-contextualized content delivery i.e. providing relevant information to the user depending on the user's task (Liyanage et al, 2009).These advancements provide a suitable platform for an Integrated Operation environment and there will be a future decline in the demand for wired and handheld instruments with the advent of such innovative and IO-efficient sensors.

CASE STUDY: SCADA MONITORING SYSTEM:

Another perfect case study is the wireless Supervisory Control and Data Acquisition system (SCADA) which is simply a system that collects data from various sensors in an offshore platform or remote locations or plant onshore and then sends this data to a central computer which then manages and controls the data and as such is a suitable tool for real time acquisition of data, monitoring and control of remotely installed systems from boilers, motors, compressors, and generators or any electrical machine and system It is designed with such simplicity it can be used by a wide range of users from the experts to operators to maintenance personnel. Data can be accessed through different sources with the use of a sensor (analog or digital). Sources could be

- Ethernet 10/100-Inserting a broadband internet cable into RJ-45 port
- SIM Card -Inserting a GPRS/GSM enabled SIM card into the slot
- Modem -connecting the data logger to a net connected through PC
- SD Card-inserting a 1GB flash card into the slot for off line data recording,
- RS-232-data can be acquired through RS-232 port.

The sensors could be analog detecting temperature, noise, vibration, fluid level, wind velocity, humidity etc while the digital sensors could be infra red, photocell etc. With the use of GPRS\GSM enabled SIM card, the user can monitor various parameters by either activating SMS alerts or email alerts to receive messages on his or her mobile phone or PDA or on the LCD screen of the data logger itself. Furthermore the accessibility to monitoring the equipment's parameters in real time by the various experts from suppliers, operators, and maintenance experts can be best done from activating a remote web account from the company's WAN or internet from which it can be monitored on a laptop or PC from the Onshore Support Center..
The SCADA system consists of four basic parts:

- The input or output devices (sensors) monitoring the equipment's parameters.
- the SCADA master unit\SCADA HMI (human machine interface) which is the main user end component of the monitoring system that provides the central processing capability for the system through which the user is able to respond to the gathered data from all networks using a browser interface thus a medium through which reports and alarms are presented to the user
- Remote Telemetry Units (RTU's) are located at specific sites and locations thus gathering information from the sensors to report back to the master units.
- Then finally the communication network providing the communication link between the RTU and the SCADA HMI.

The major advantage of the new SCADA system is its support for a variety of open-source protocols and devices. Protocols such as the IEC 60870.5 standard or even propriety protocols (could exceed 25 supported protocols) and devices for example the distributed security architecture (DSA) developed by Honeywell consists of the integration of DCS and SCADA system to form a single virtual machine. The SCADA system prevents the system from going obsolete and is suitable for the OLF integrated operation plan of shifting from one OLF generation to another thus a cost effective monitoring system for the future. The system is also suitable for monitoring both auxiliary and critical machineries just like the Bently Nevada system.

5.4 ENABLING COMMUNICATION INFRASTRUCTURE & OPEN STANDARDS FOR SYSTEM INTERFACE CAPACITY

With respect to e-operation capabilities for ensuring easy collaboration with the various stakeholders, the present condition monitoring technologies are supported by enabling technologies from wireless networks, field bus, RFID tags, handheld devices(HHD) with smart user interface such as portable mobile cameras, PDA's, computers, voice data etc. such that information can be transferred from offshore to the onshore support centers thus making the connectivity between the field operators and remotely located experts efficient. Enabling telecommunication technologies with both data and voice access such as the WiMax which is presently been operated at the BP-Valhall platform and the wireless LAN(WLAN\802.11g) employing a new standard called the IEEE 802.11n with greater range and improved capabilities in data rates are highly efficient communication technologies enhancing e-operations offshore. RFID as discussed above consists of both an integrating circuit for information processing and storage and the other for receiving and transmitting signals and is the ideal technology for linking offshore and onshore operations more effectively and can accurately transfer real time or near time information between the offshore assets, supply chain partners and service organizations. More so the availability and general utilization of these open standards from systems (W3C-World Wide Web) which provides web-based solutions for the establishment of supportive expert networks to industry standards and protocols like WITSML, PRODML, field bus, industrial Ethernet etc. Compared to propriety standards they contribute significantly to e-operations. For example Field bus IEC 61158 especially the foundation field bus which is now common in the oil and gas industry offers a powerful diagnostic feature which is a perfect technology for remote performance management thus reducing routine checking and unnecessary inspections. Its digital communication protocol enables multiple field devices to communicate through same pair of wires thus reducing hardware or cable cost. Common open or free protocols like the Extensible Messaging and Presence Protocol (XMPP), an XML-based protocol for real time instant messaging used for information sharing between different computer types, application and organization does not need to pass through many layers of conversion unlike the propriety protocols and have also made monitoring, telemaintenance or e-collaborative technologies suitable for e-operations.

The open standards or standardized technical platforms are currently been utilized in the oil and gas industry although it benefits the operators the most such that they will be able to own their own data and information rather than being dependent on vendor-driven formats or non-open (propriety) systems thus reducing the fear of losing these data in the case of contract termination between both parties or loss of hardware or reports containing such data. The integrators also stand to benefit such that they are capable of offering cost effective integration projects with the use of open standards rather than developing point-to-point interfaces which are rather expensive. Platforms based on semantics and ontology for data exchange currently been adopted include the ISO 15926(for industrial automation systems and integration) used for data integration, sharing, exchange and transfer between computer systems, ISA S88/S95,IEEE 61970/68- for asset and physical hierarchy representation, Production Optimization Markup Language(PRODML),Well Information Transfer Standard Markup Langauage (WITSML) etc. The PRODML & WITSML is currently been used by Kongsberg for its vendor-neutral real-time data management system which gives the service providers, engineers, collaborators access to log into the system to proffer quick intelligent decisions. These semantic web-based technologies are known to enable access to maintenance and production data respectively. Other examples include the recently introduced ABB wireless vibration sensor using the WirelessHart open wireless communication technology which enhances more predictability and flexibility to use sensors from several vendors in the same communication network. (Birkemoe, 2009).

In general, the IO suitability and advantages of these open standards are such that there is no chance of vendor monopoly or it been locked-in by a specific technology and as such easy for a third party to implement same solutions by following the same standards since the specifications, interfaces, guidelines or rules are open and known. More so, it allows for easier interoperability and communication between different systems and parties enabling improved data interchange and exchange between them and therefore does not limit software usage to one particular vendor to either read or write data files and such interoperability requires less retraining prior to usage by its respective users. Furthermore in the event of obsolete applications, these data files can be easily converted to be used for a new application thus eliminating the exorbitant cost of converting these files. Finally open standards give the vendors and other stakeholders opportunities to offer various solutions and a possibility for creativity such that a particular mix-match solution could be created from multiple vendors which could be the best breed of standard. This has enabled collaboration between leading automation organizations consisting of the Fieldbus foundation, HART and PROFIBUS to develop a specification for a common interface to a wireless gateway which will be based on the WirelessHART technology and the emerging ISA SP100.11a standard.

There is also an availability of numerous systems to user interface designs suitable for e-maintenance solutions such as Textual User Interface(TUI),Command-Line Interface(CLI),Graphical User Interface(GUI),Interaction Design(I*x*D),Experimental Design, Information Design, Graphic Design and finally the User Centered Design(UCD).(Liyanage et al,2009).Though the GUI seems to be the preferred CBM user interface for most industries since charts are the most common method of presenting CBM information to its users and can be applicable for presenting discrete values, alarms, graphics, animations etc (Philip et al, 2004).Finally, the establishment of the highly dependable, reliable and secure digital infrastructure known as the Secure Oil Information Link (SOIL) has enabled easy data accessibility, collaborative accessibility and access to the required competences and expertise in the oil and gas industry. The SOIL network presently has about 170 companies as members and creates a suitable platform for the successful take off of e-operations.

5.5 HIGH LEVEL OF INTEGRATION TO REDUCE COMPLEXITIES AND INCREASE EFFICIENCY:

Within the O &M industry, there is a high level of integration of systems, technologies which will enhance the smooth functioning and performance of e-operations both now and in years to come. Integration levels vary from:

- Integration of wireless technologies with sensor and mobile computing devices as described above.
- The integration of applicable industrial information standard which is necessary for the successful exploit of wireless and mobile computing to enable interoperability and exchange between different users and so is the development of suitable or best-breed standards to enable integration with PAM or CMMS systems.
- Integrating respective data from different sensor sources to provide a single data base able to give a holistic machine health condition which is possible with the use of advanced software technologies.
- Integration of condition monitoring information with plant management systems or computerized maintenance management system or integrating performance and process monitoring system with existing vibration systems enabling a single user interface and alarm handling method. Either way they all provide a holistic picture approach unlike stand-alone systems thus making it easier to establish results from different monitoring techniques for fault detection and a more reliable diagnosis.

- Integrating various logic, models and expert knowledge and technological solutions into a system. These systems are called Intelligent Maintenance Systems.

There are newly advanced systems with the above integration capabilities and also capable of utilizing such standards and possess other e-operation requirements. Such systems are known as intelligent systems (IMS).IMS systems such as the watchdog agent-based Intelligent Maintenance Systems can be said to be the ideal e-monitoring equipment for both the present and the future.

CASE STUDY: THE WATCHDOG AGENT-BASED REMOTE MACHINERY PROGNOSTICS AND HEALTH MANAGEMENT (R^2 M-PHM) SYSTEM

The watchdog agent is a product of the Intelligent Maintenance Systems (IMS) center at the University of Wisconsin-Milwaukee and CBM lab at the University of Toronto. Its mode of operation is such that it utilizes three different intelligent concepts that make it the ideal e-operation tool for the future. These concepts consist of machine intelligence, operation intelligence and synchronizing intelligence. Apart from the functional intelligence possessed by most condition monitoring equipment such that they are able to remotely monitor, acquire data and diagnose equipment faults, the strength of watch dog agent lies in the ability to exhibit both functional and human information intelligence. Human intelligence is a combination of prognostic and degradation assessment such as health assessment, performance prediction, failure prediction and the ability to interact with the functional intelligence. The watch dog agent is capable of reconfiguration, compensation, and self-maintenance and also can determine the root causes of failure. Operational intelligence on the other hand is its ability to set priority, optimize and proffer responsive maintenance scheduling in dynamic environments where different machines are to be considered in the event of degrading health condition or near failure machine conditions. While the synchronizing intelligence enables automatic flow of information between production and demand such that it could automatically trigger service and order of spare parts.(Lee and Ghaffari, 2007).

The watch dog agent is a toolbox of prognostic algorithms as well as remote and embedded predictive maintenance technologies that can autonomously access and predict the performance degradation and remaining life of machines and components. It is a combination of both hardware and software whose system architecture comprises of the following:

- **Embedded software consisting of watch agent toolbox, database, decision support tools and web server**.

The database helps to save health related information while the decision support tool enables fast decisions and actions to be carried out in response to alarms or warnings of which the exposure to risk is higher in a 24\7 online real-time environment than under the traditional operating condition(Liyanage et al, 2009) therefore the decision support tool assists the operating personnel in balancing and optimizing resources in the event of expected multiple equipment failure and also assists the logistics and production managers to optimize their maintenance schedules so as to minimize downtime costs and productivity losses. The web server enables accessibility to the necessary maintenance information through a device-to-business (D2B) system level interconnectivity to respective computers and remote locations or onshore centers and is the key IO enabler in the system. The toolbox consists of both signal processing and feature extraction tool and performance assessment tools. The latter consisting of performance prediction and prognostic software models such as:

- ❖ Neural Networks, Match Matrix, statistical pattern recognition, Fuzzy Logic, Autoregressive Moving Average which are used for performance prediction.
- ❖ Bayesian Belief Networks, Support Vector Machine, Hidden Markov Models (HMM) used for health diagnosis.
- ❖ Logistic Regression, Self-organizing Maps(feature map pattern matching), particle filter based performance assessment are the performance assessment tools

While the Signal processing and feature extraction consists of Fourier Transform, Time-Frequency Analysis, wavelets packet energies and tree decomposition etc

- **An embedded operating system or real time operating system (RTOS) and embedded computer:**

The key components are Advantech's UNO-2160 or UNO-2170, both embedded automation computers with Intel Celeron processor and CeleronR M processor respectively. They both support WindowsR CE 5.0, XP Embedded, and Linux ready solution. Also included is the PCM-3718H, a 12-bit DAS module with programmable gain. (Advantech eAutomation, 2009)

<u>Watchdog agent system interface connectivity-Solution to propriety standards</u>

Most manufacturers use a propriety communication protocol which leads to difficulties when connecting different machines and products to the IMS system. Therefore to curb such difficulties a standard web-enabled remote monitoring device to business platform (D2B) has been developed. It is known as the IMS infotronic platform which includes both the watch agent tool box and the D2B system level interconnectivity and is thus able to transform product conditioning data into useful health information format for remote and network enabled prognostic applications.(Liyanage et al, 2009).

The Watchdog Agent follows an open architecture design which allows new tools to be added and existing ones to be disabled easily depending on the application. The user's input can be captured based on a Quality Function Deployment (QFD) selection tool which aid in tool selection for rapid deployment in case of the user not having thorough knowledge about the algorithms.

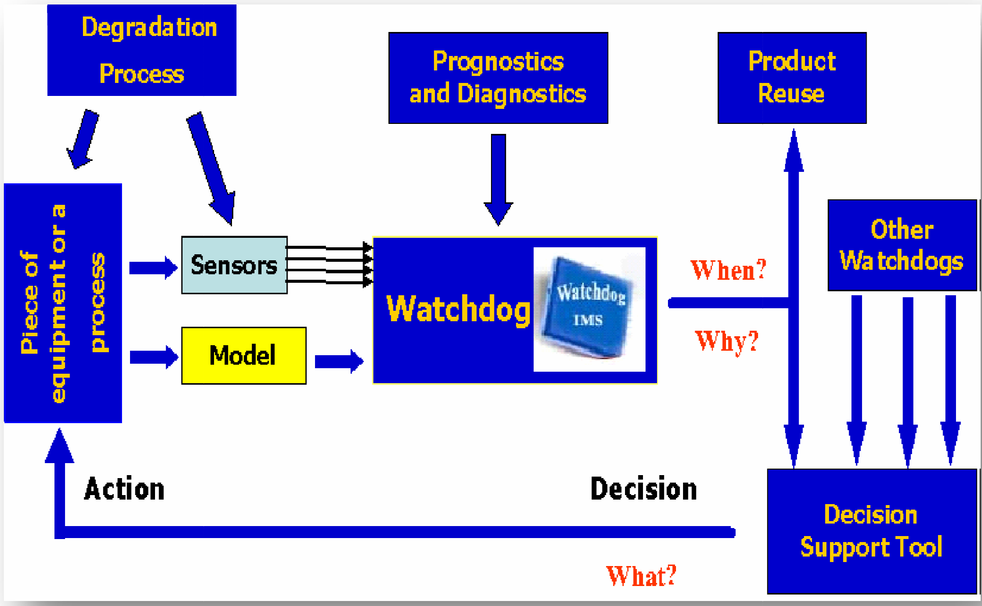


Fig. 17.0 Key elements of the Intelligent Maintenance Systems (IMS Center)

From the sensor inputs mounted on the watchdog agent, it is able to predict the process or performance of the equipment since it is obvious that performance degradation is a distinct symptom of equipment failure and as such is used to predict unacceptable system performance before failure occurs. Therefore it predicts when and why the system or equipment is going to fail and uses the decision support tool to find the solution to what probable maintenance actions will be required for the equipment which could possibly be service or spare parts order.

The diagram in ***figure 17.1*** below gives a detailed representation of the watchdog agent from which performance related information is extracted from the multiple sensors through performance assessment tools comprising of the signal processing, feature extraction and sensor fusion techniques. Historical behaviors obtained from the process signatures are used to predict their behaviors and predict the machine or equipment performance whereby based on this predicted performance, proactive maintenance is made possible through the prediction of potential failure prior to occurrence. The proactive maintenance infrastructure can be supported by the information learnt at the watchdog and this Peer to Peer (P2P) paradigm will be used to improve the diagnostic and forecasting functionalities of the watchdog agent.(Ni et al,2002). Therefore the watchdog agent stands as the best integrated condition monitoring system for today's industrial applications for monitoring both dynamic and static systems. From providing multi-sensor assessment to assess the various parameters which may affect the plant to its use of specialized prognostic and diagnostic software models most particular the artificial neural networks (ANN) which is far superior to other models due to its distinctive capabilities of fault tolerance and analysis of complex networks such that it is able to identify specific indicators even with the introduction of new or advanced systems or equipment.

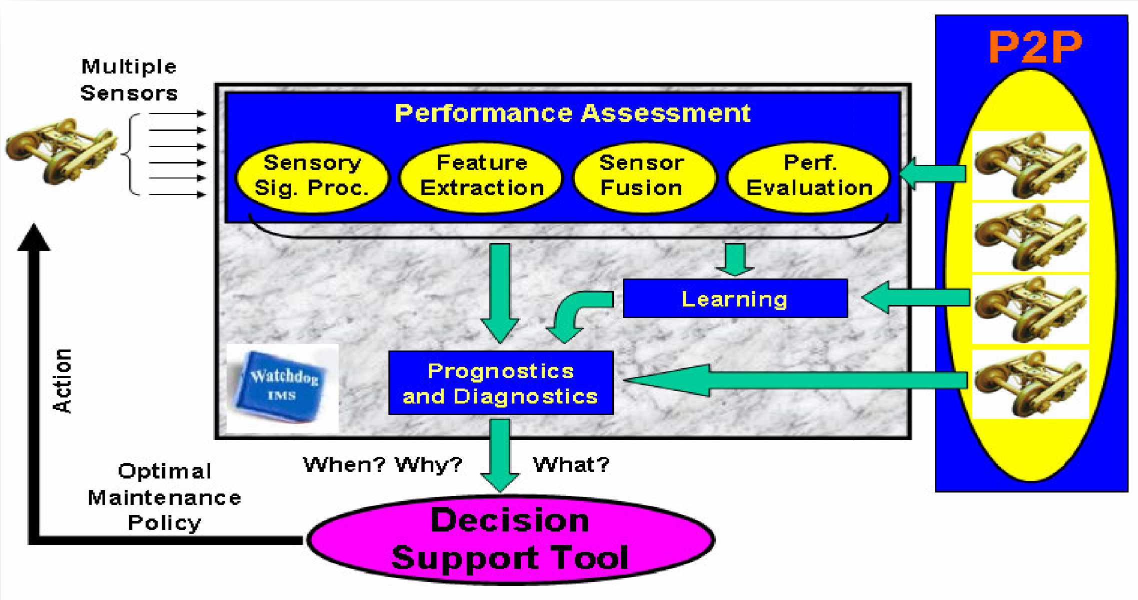


Fig. 17.1 Schematic representation of the Watchdog Agent (IMS Center)

In summary the latent characteristic of both monitoring and enabling technologies such as the ANN and Open standards is their flexibility and ability to accommodate advancing technologies which would be perfect in the event of brown field development such as BP-VRD or OLF generational changes from generation one(G1) to two(G2).

CHAPTER SIX
ROLE OF CONDITION MONITORING VENDORS IN INTEGRATED THE OPERATION VALUE CHAIN

6.0 ROLES AND RESPONSIBILITIES

The role of monitoring vendors in the oil and gas industry is been viewed mostly in terms of outsourcing where the operation and maintenance part of the business are being contracted to these vendors by the operators but with the adoption or redevelopment of most facilities or field to an integrated or smart field which in recent times is common to brown fields such as the Valhall Redevelopment (VRD) project, there will be a larger role to play for the take off and success though the IO concept would be most appropriate for Greenfields in terms of low cost as compared to the brown fields. However, in both scenarios condition monitoring vendors will not only be taking part in offering maintenance services to the end users or operators but also involved in early planning and development of smart fields from feasibility, conceptual studies, operations and possibly decommissioning phase. These vendors will be seen not only as service providers but partners in the business having a stake not only in the accrued benefits but also in the risk involved. Therefore adopting integrated operation would lead to consequences which would assign new roles and responsibilities for both suppliers and manufacturers of condition monitoring equipment and services.

6.1 EFFECTS OF INTEGRATED OPERATION ON CONDITION MONITORING VENDORS

The adoption of integrated operations would lead to:

- Changes in work processes as a result of integrating different disciplines and processes together,
- Transfer of functions from offshore to onshore and
- Will open up new possibilities for condition monitoring vendors such that new business models, contracts and incentives will need to be created.

Condition monitoring vendors will have to take up new and extensive roles and responsibilities which would involve closer integration with the operators and more involvement in the decision making process from project conception to the decommissioning phase. Furthermore the major demand for vendor expertise would be in the development and implementation of new condition monitoring technology, remote operation and support services. Transfer of functions onshore would lead to most of the operators and vendors requiring few offshore personnel and more operative positions onshore which could require shifts to meet up with the 24\7 monitoring. Though for the personnel, offshore bonuses will no longer be applicable and would save cost for the operators both in terms of these benefits though a reduction in employment of offshore personnel is likely but there will be better utilization of competence and increased coordination of work between the operators and vendors.
The shift in work process would be from series to parallel work process which would require versatility and flexible skills, a shift from offshore decision making and onshore

support to onshore decision making and offshore support of which decisions would be based on real time information rather than experience which was the conventional norm. (Fjærtoft, 2006) Onshore support on the other hand would require interdisciplinary teams working together both from the operator and vendors through the use of onshore support centers which would be the central node for e-operation and maintenance.

6.2 CHANGE MANAGEMENT AND IO:

It is of great importance to know that the early stage of an IO driven project is critical for successful implementation and would require a re-phrase of the operational philosophies adopted in previous project development stages such that roles, responsibilities and autonomies of the various stakeholders such as vendors, operators, FEED contractors, and suppliers would need to be changed with keen attention on the suppliers of automation and ICT infrastructures. Operational philosophies consists of the operational ambitions which in this case would require remote operational support, remote performance and maintenance management, integrated decision making, collaboration between different disciplines and organization backed with a contract support strategy such that the CM vendors are involved in the remote operation support. A major challenge in the change management process would be during the operation phase where interdisplinary experts are to be involved in decision making processes (mirroring OLF G2). The generation 3 (G3) phase of having different experts in the same center seems more like a fantasy thus shows that the challenge for every generation phase lies in changing the mindset of the various stakeholders involved.
However, in order to ensure that the roles and responsibilities assigned to the various multi-disciplinary groups are properly coordinated, a change management tool known as CORD MTO was developed by a group of research firms consisting of MARINTEK, SINTEF and IFE and is used to analyze and support such a change process. CORD MTO is a guideline used to analyze the various functions and helps to allocate these functions for an integrated operations setting. It combines human, technology and organizational aspects to identify how resources can be efficiently and optimally distributed amongst the various functions performed both offshore and onshore putting into consideration the roles of the stakeholders and organizations. Furthermore the CORD MTO will play a major role when adopting new technologies in the event of transition from one generational phase to another which will definitely lead to changes in work processes.

MARINTEK was the facilitator for the change management process within the scope of IO for the VRD project.

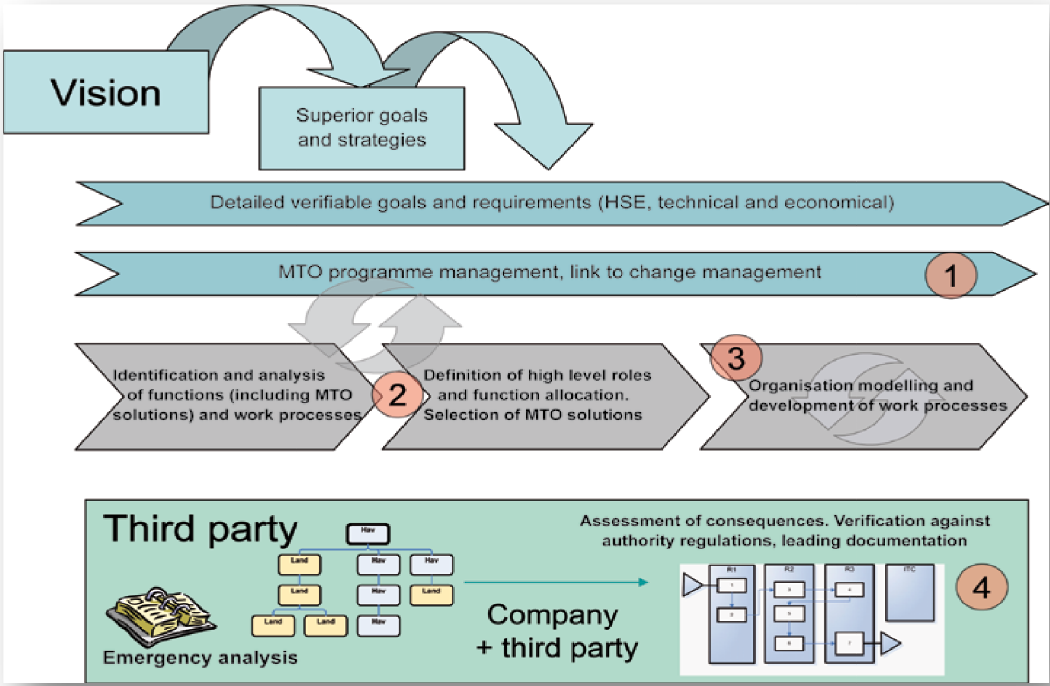


Fig. 18.0 Schematic overview of the CORD MTO method. (Marintek Annual Report, 2005)

6.3 OLF INTEGRATED OPERATION STANDARDIZATION

The integrated operation standardization document was prepared by a small core team of experts of the Norwegian Oil Industry Association (OLF) as a guide for the implementation of integrated operations into major capital projects and is still been reviewed. It has given vendors and end-users insight towards maximizing IO potential in projects and the strategic steps towards achieving the desired IO objectives of the various end-users thereby ensuring that IO philosophies, practices and application technology are integrated into new development projects from their initial stage. It is of interest to note that it is not an obligatory standard but a tool towards maximizing full IO potential.
The drafts version presents the components of IO in form of the triangle illustrated below in ***figure 19*** which gives a holistic asset performance from the acquisition and conversion of raw data to information needed by the experts in order to make real time decisions which are supported by collaborative and IT architecture and infrastructure. This triangle provides the road map towards attaining the business goals in terms of O & M and shows the increasing business value from data acquisition to making real time decisions.

From the standard document three aspects of IO in the project development process have been specified.

- The operational philosophy which identifies the IO ambitions
- IO design methodology-transforming these ambitions into solutions

- Major emphasis on front end engineering design of key resources.

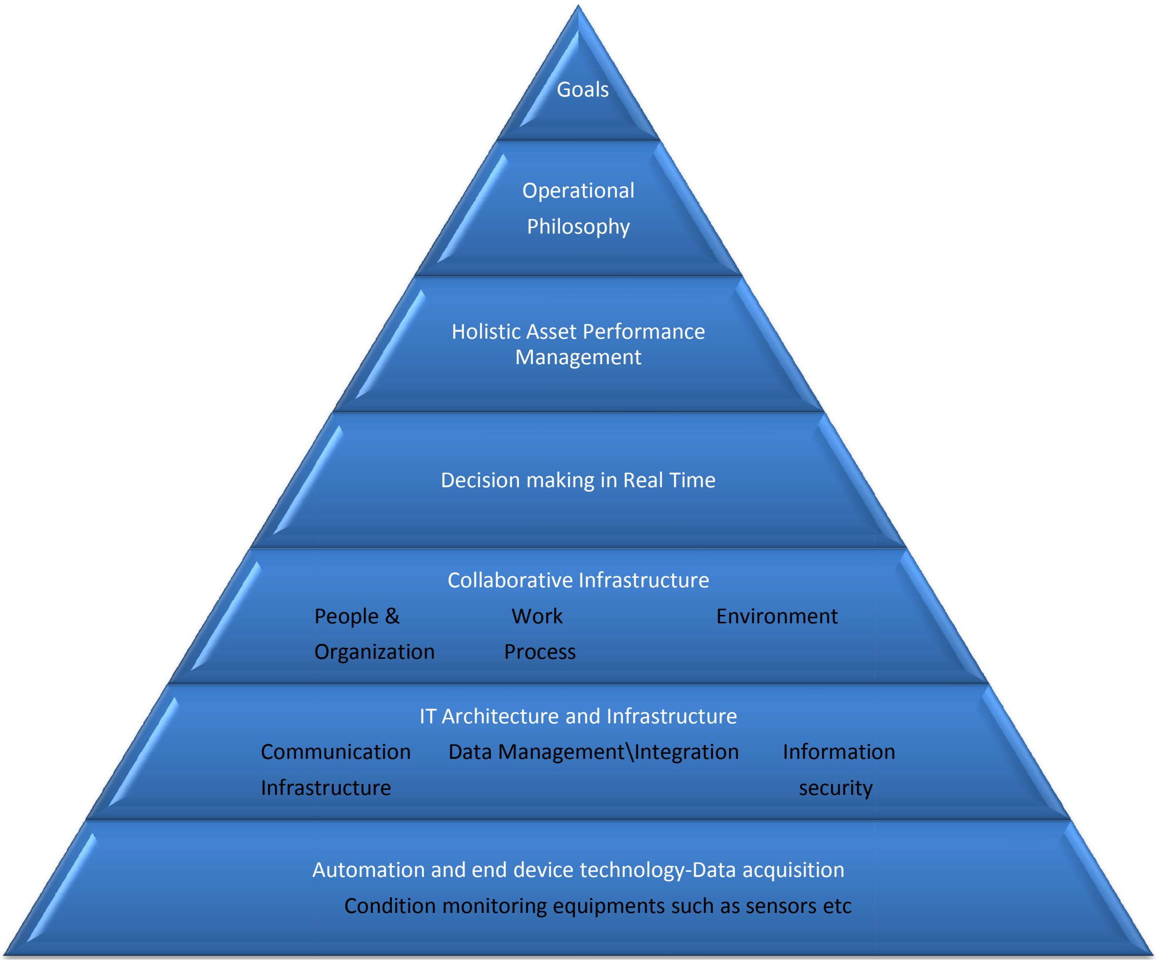


Fig .19.0 Road map towards attaining business goals (OLF, 2008)

According to the OLF standardization for integrated operations, to achieve a successful IO driven project it is necessary to develop guidelines on how the assets are to be operated which will enhance the selection of requisite technology and work process required to achieve this project. These guidelines are otherwise known as operational philosophies. However the most critical phase for vendor participation would be the feasibility phase which would be the determinant factor towards a successful IO project. From identifying the critical IO ambitions and possibilities, operational philosophies can be established that gives a reflection of the intended IO ambitions of the project and thereby enabling early definition of the organizational structure and work process and thus enhance early pre-project planning at stage where design changes are still possible.

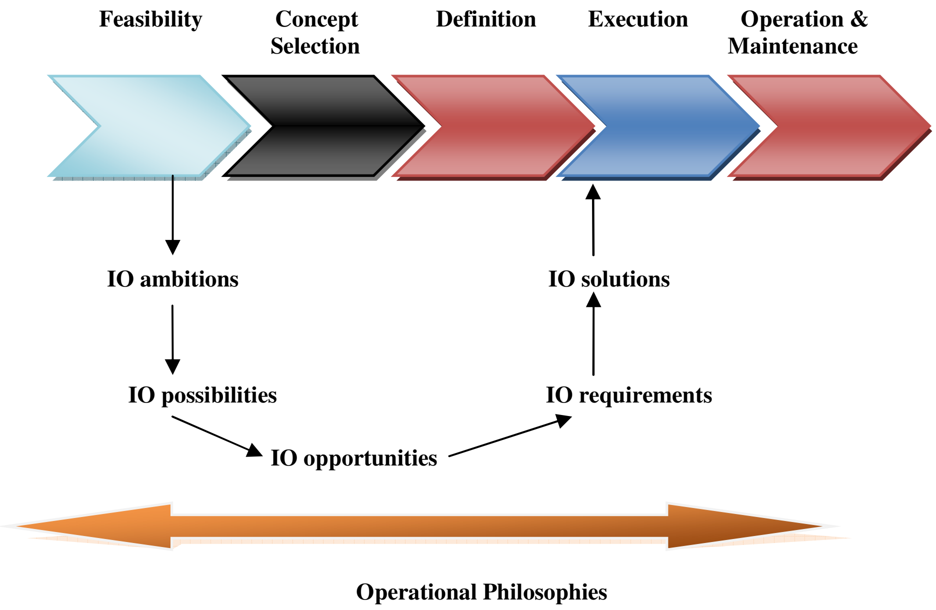


Figure 19.1: IO value chain (OLF, 2008)

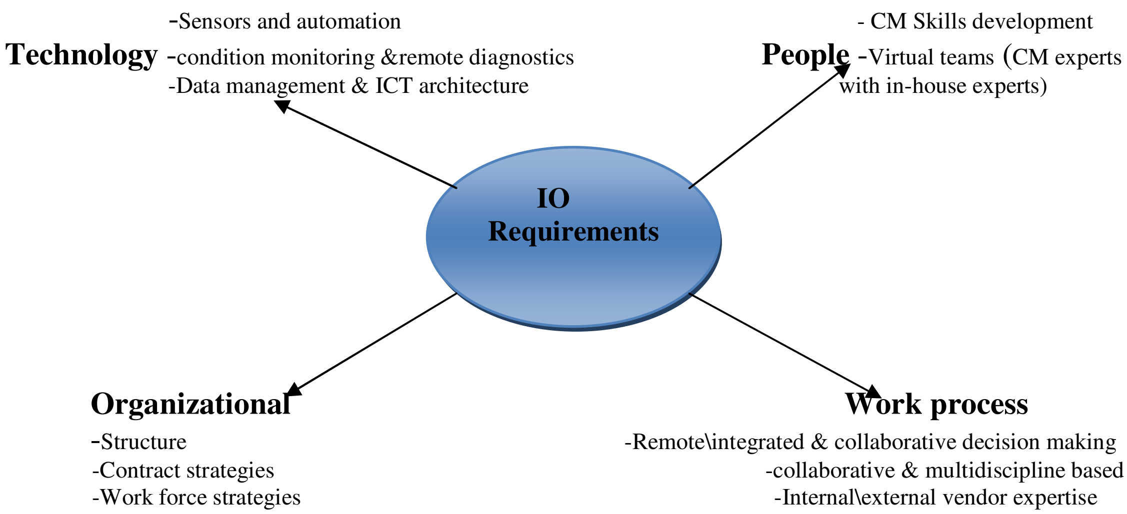


Fig: 19.2 IO requirements

From these four areas the IO ambitions and requirements are further established and the IO project team is able to identify the necessary inputs required for the IO project. Furthermore these philosophies would require a change management process as discussed above where new roles and responsibilities would be developed and assigned to the various stakeholders owing to the changes in organizational structure to support the work processes which will lead to new contractual agreements, service offerings etc.

6.4 OVERVIEW OF THE MAJOR LIFECYCLE PHASES FOR VENDOR PARTICIPATION

In analyzing the value chain of the Integrated Operation concept, one considers the various activities and work processes required to develop a smart integrated setting. This value chain can be divided into both primary activities and support activities. The primary activities are those activities that are concerned with creating and developing the needed tools in terms of products and software for integrated operation. These products refer to the condition monitoring equipment and technology, information and communication systems, automation and instrumentation that would be required. On the other hand, support activities refer to the tools necessary to enhance operational efficiency and cost effectiveness of the project. Therefore having an overview of the entire lifecycle development of any project, we consider the three major phases involved from feasibility to the decommissioning phase to identify possible areas where vendor participation is necessary for successful implementation of the e-monitoring project.

Fig. 20.0: Three major phases for IO project development

According to the IO design methodology, insufficient front end engineering design (FEED) from operators and vendors will be a limiting factor towards full IO potential and a slow uptake of novel technologies and work processes. (OLF, 2008).Therefore the Integrated Operation standardization document was developed for both the operator and vendors to curb these shortfalls during the project development phase by incorporating IO considerations into their asset operational philosophy.

6.5 CONCEPTUAL DESIGN AND CONSTRUCTION PHASE

This phase would consists of feasibility, concept selection and definition, FEED studies, Detail engineering, procurement and logistic planning, construction, installation and finally start-up.

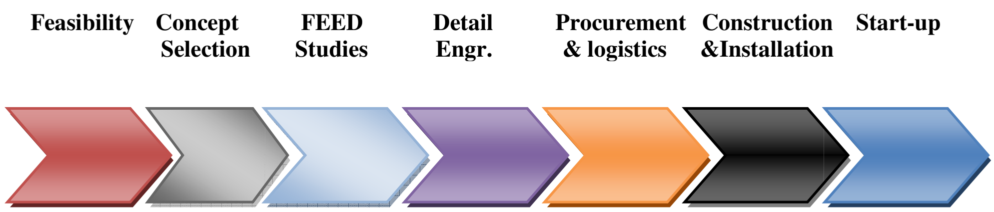


Figure 21.0: Conceptual design and Construction phase

6.5.1 FEASIBILITY STUDIES

For an innovative project it is necessary to carryout feasibility studies concerning probable equipment, human and technological options capable of achieving the specified IO project objectives. This feasibility studies must be carried out based on the overall IO ambitions of the project i.e. for a project like Goliat, employing a remotely operated floating facility would be most suitable thus if the operators are keen to adopt this IO methodology, the condition monitoring vendors must align its feasibility studies based on the overall IO ambition. According to the OLF, the first phase of the integrated operation project is the generation 1(G1) which is aimed at integrating work processes and infrastructures or systems of which the systems has to conform to the operators requirements so as to enhance an effective and efficient system interface between that of the end user and the vendor. Therefore the necessary standards, automated systems and other viable condition monitoring technologies capable of achieving the desired objectives have to be identified at this stage. Vendor participation at this stage is important though could be independent such that feasibility studies should be undertaken by the vendors after carefully reviewing the tender requirements for a particular IO project.

In essence, feasibility studies must include the requisite condition monitoring equipment and technology suitable for the IO project i.e. not only selecting advanced technologies but the application technologies with the capacity of achieving the projected IO ambitions of the operator or end-user.

With reference to equipment applications or features, an IO-condition monitoring equipment and technology should be able to:

- Handle large amounts of data and automatically gather these data from various multiple data sources into a centralized system. This enables easy and quick access to the monitored equipment data.
- Due to these large amounts of data some condition monitoring programs experience data overload which could produce ineffective programs therefore technologies able to filter these data from errors is a necessity.
- Integrate to other business systems using similar information i.e. system interface capacity.
- Use of intelligent systems capable of applying logic to detect equipment conditions that require maintenance intervention. These systems assist and support asset team and make up for present and future expert decisions.
- Also must be able to automate repetitive tasks so as to save time.

Optimum criteria for selection of monitoring equipment must also tend towards Human-Technology-Organization (HTO) concepts such as equipments with ergonomic design able to meet the specification of the adopted IO architecture, the end-user's organizational structure, enable easy training of staffs on CBM methodologies etc.

Feasibility studies must also consists of the required skilled manpower, a review of monitoring equipment and technology with several performance options including cost and energy analysis fitting in the tender requirements and with the technological capacity of fitting into the generation two (G2) plan if possible. Therefore it will be of immense benefit for collaboration between the suppliers of instrumentation systems, the ICT systems and CM vendors after bids have been accepted by the end-users or operator. For the brown field Golait project, the operator, ENI Norge have adopted a floating production and offloading vessel (FPSO) with subsea wells from contractor Sevan Marine AS which seems to be the ideal field development solution not only because of it's a small field (15-20yrs) but its suitability towards an integrated operation concept because of its location in an unfriendly environment. Case histories have shown that FPSOs can be manned with only one oil company person on board having the responsibility for all operations - from hookup to the subsea wells, to FPSO operation, to shuttle tanker export - being shouldered by a contractor (Lovie, 1998).

The IO architecture suitable for the Goliat field would be the OLF generation 2 phase which would facilitate the use of limited operational personnel. Using the OLF document as a guide:

- **IO ambition:** Limited manpower and remotely operated facilities due to the region which is extremely cold, unfriendly and environmentally sensitive.
- **IO Possibilities:** Therefore IO possibilities will consists of full vendor remote support and operations from shore to be located 85km northwest of Hammerfest or can be connected to the support center from the Snøhvit field (50km south east) from which other integrated field planning and logistics activities could be done together with remote performance measurement of the facilities etc

Therefore using these ambitions and possibilities as a guide, the plan for development and operation (PDO) would be drafted containing the operational and maintenance philosophies, potential for connecting the field with other fields or installations and third a collaboration center for the Goliat project and also should contain the possible condition monitoring equipment, support and logistic arrangements.

6.5.2 CONCEPT SELECTION PHASE

Concept selection phase would involve major participation and early involvement of key experts involving the monitoring vendors and operators. In this phase the most viable condition monitoring equipments and support options from the list of possibilities are selected. From the IO standardization document, the following is a list of activities the condition monitoring vendor is expected to be a part of:

- Under the supervision of an IO team leader, the expected roles and responsibilities for the IO activities are to be defined with the condition monitoring expert taking into cognizance its major roles and responsibilities.
- IO possibility assessments i.e. further possibility assessment is put into consideration by the monitoring expert against criteria such as business benefits, environmental considerations, operational impacts, project execution, addressing people, process, technology and organizational constraints.
- Recommend IO opportunities for concept selection.
- Update IO strategy and plan

- Prepare information management strategy or plan
- Carry out a RAM analysis including the selected IO opportunities.
- Identify major work processes with IO impact taking into consideration operational decisions and competence requirements.
- Develop key IO requirements for communication and collaboration facilities.

6.5.3 CONCEPT DEFINITION PHASE:

This phase primarily is concerned with activities or requirements associated with IO opportunities that are necessary for design and project execution. The concept definition phase involves re-enforcing alignment between the established operational philosophies and the overall requirements of the project, refining the IO possibilities, developing the functional requirements and identifying the impact of the IO requirement on monitoring equipment procurement, training and staffing .(OLF document, 2008).Therefore this phase would require the collaboration of both the operators, contractors, condition monitoring vendors and other stakeholders of which the monitoring vendors are expected to be part of the following activities in the IO team.

- The IO team should present the IO plan and IO strategy for asset management so as to get management support and feedback.
- The IO team is expected to undergo a system review process for the IO project ,the vendors together with the feed contractor are expected review the systems and equipment, analyze competency requirements and suggest possible control devices and associated data requirement which may improve monitoring and control of operations and maintenance.
- Data requirements and tools are further defined for operational decisions thus instrumentation and analysis tools are identified as basis in the key work processes.
- Technology gaps associated with the selected IO solutions are been considered and it is also necessary that the vendors perform a review of current R &D to ensure the project is current with the relevant developments or updated technologies and systems.
- Functional requirements for instrumentation, communication, collaboration infrastructure, analysis tools and IT plan are developed putting into consideration their respective standard requirements for approval.
- Further specifications or requirements are established that are critical for detail engineering and procurement and a technical review of how compliant the IO project is. Further recommendations and verifications of these requirements shall be done by the FEED contractor to ensure that the IO requirements critical for the project procurement and execution have been met.

6.6 PROJECT EXECUTION: PROCUREMENT\LOGISTICS\INSTALLATION AND START-UP

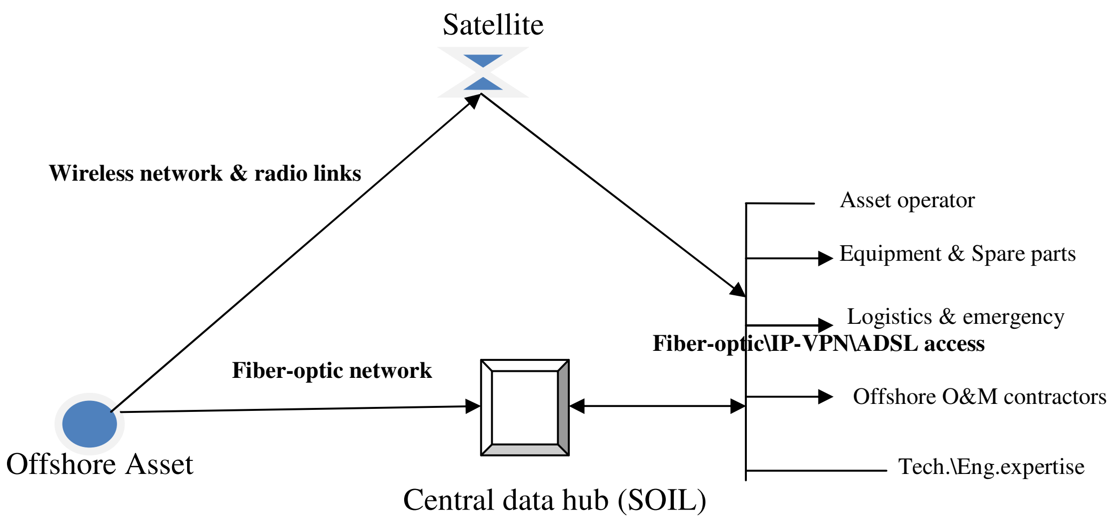
Furthermore, vendor services could involve developing the necessary work process for the operation phase using established industrial guidelines and standards such as the ISO 6385 and others which addresses H-T-O issues such as communication, collaboration between offshore and onshore personnel and also between plant operators and covers issues. This is achieved by:

- Defining vision, strategies and goals,
- Data gathering, functional analysis and allocation of task allocation.
- Organizational modeling and new work process development.
- Consequence analyses.

Such reviews would enable offshore work task to be transferred onshore and open up possibilities for automating the work task if necessary. The need for integrated planning is crucial for successful implementation of an IO project therefore achieving this objectives would require setting up an onshore support center from which activities can be coordinated such as logistics and expert support and a center with the capacity to address any deviation from the stipulated IO ambitions. Integrated planning could also be achieved by developing a cyclic inter-discipline planning process. (OLF document, 2008)
Maximum collaboration is required between the suppliers of automation and monitoring systems during construction and installation so as to ensure the required system interface specifications and other system requirements are in accordance with plan.
Condition monitoring vendors would be needed to provide design optimization and verification expertise such as carrying out virtual equipment testing in the computer or "real" testing in their intelligent test bench and developing a test strategy to validate equipment design before any start-up or commissioning. By using a prototype, the vendors can evaluate the performance of the tested components and proffer reliable recommendations. Other testing like lubricant testing can be carried out on the bulk equipment to find out suitable lubricants.

6.7 OPERATION AND MAINTENANCE PHASE

This is the phase with maximum vendor participation and support and where vendor input to the IO value chain is most needed and can be coordinated with the establishment of onshore support centers(OSC).From monitoring machineries, pumps and critical equipment, to offering expert services, following up condition based maintenance (CBM) procedures and logistics support etc though with the recent advancement in condition monitoring technologies, there will be less movement to and fro offshore installations. This integrated operation concept breaks down the previous modus operandi between the vendors and the operators whereby the data obtained are delivered to the operators by the vendors, the operators and other stakeholders have easy access to their equipment's data with the aid of open data system such as the Secure Oil Information Link (SOIL) which acts as the central data hub currently been used. Therefore with the use of wireless technology\network the O & M phase is established.



Advanced fiber-optic & wireless ICT network

Fig. 22.0: Technical infrastructure for integrated e-operation solution (Liyanage et al, 2009)

Sources of data from the offshore asset which could be from the distributed control and monitoring systems, experience data, direct visualization, offline-online technical data, data from intelligent systems and components etc can be easily transmitted to a net based web-enabled ICT system(SOIL) through fiber optics and these data can also be tapped through various mediums by other experts or stakeholders on the onshore support centers(OSC).Communication through videoconferencing is made possible with the aid of the satellite which could connect a personnel offshore or offshore support center with others onshore to make up for proper collaboration and integrated work process between the stakeholders in ensuring proper data-to-decision(D2D) and decision-to-action(D2A) processes.(Liyanage, 2009).Therefore depending on the IO architecture, some vendors like SKF have its online support center(OSC) linked to offshore centers from which they are able to communicate with experts onshore and also monitor the equipment while some onshore OSC's could be based at the premises of their operators or service-support or supply organization from which they are connected with the offshore control rooms and equipment.

Therefore condition monitoring vendors play a major role in this phase from establishing business-to-business partnerships with the operators and such roles includes:

- Online monitoring of offshore equipment such as vibration monitoring services, thermography services, corrosion monitoring services etc and condition assessment services of both critical and non-critical equipment.

- Offer consulting services which could range from designing and implementing sampling programs to machine failure investigations such as troubleshooting to find out the causes of equipment failures develop maintenance programs, and carry out root cause analysis (RCA) etc.
- Other operational roles would consists of logistic support and handling
- Emergency response and remote instructions for tasks requiring specific competence.
- Offering 'maintenance-knowledge' transfer services which could be on-the-job knowledge transfer services or remote field training from the onshore support centers which can be done without reducing service quality or obstructing on-going production at the platform

6.8 DECOMMISSIONING PHASE

This is the final phase of the project where operators are solely responsible for determining the decommissioning date. Though not much roles are available for the condition monitoring vendors but the major phases are likely-the planning phase, deactivation and clear-out phase.

6.8.1 PLANNING PHASE

This phase begins early before the permanent shutdown of the facility and primarily for the condition monitoring vendor, the various tasks could involve carrying out plans for deactivation, cost benefit analysis of critical equipment such as turbine generators, pumps etc for the operator to decide if these equipment could be reused for another project, sell it off or dispose it. Condition monitoring vendors can test the efficiency of these equipments and thereafter plan on what measure to take from the result of the cost benefit analysis. Other tasks could also involve ensuring that operation and maintenance data has been converted and archived in an application-neutral format while those required for continuing analysis is available to the operators thus it is necessary to carry out data audit to ensure any data transformations is identified so as to recreate the original data values.

6.8.2 DEACTIVATION & CLEAR-OUT PHASE

This involves shutting down operation and maintenance activities, removing and disposing equipment such as sensors and other condition monitoring equipment that was used for monitoring the plant or asset.

CHAPTER SEVEN
RECOMMENDATION ON THE APPLICATION OF CONDITION MONITORING EQUIPMENT FOR INTEGRATED OPERATIONS

7.0 THE FUNDAMENTAL STRUCTURES FOR IO SUCCESS.

To fully implement an integrated e-operation-e-maintenance structure apart from the use of advanced application technologies capable of providing smart O &M solutions suitable for IO, other integral components that have to be set up for the technical foundation and take off of e-maintenance include:

- The use of onshore condition based maintenance (CBM) expert centers equipped with high technology equipments capable of analyzing & interpreting data and even troubleshooting and from which integrated planning can be done.
- Digital IT and communication infrastructure- implementation of the large ICT network known as Secure Oil Information Link(SOIL) which is a fiber–optic technology enabling the transfer and exchange of data in real time. Other ICT communication technologies include the very small aperture terminal (VSAT) networks which can transmit voice, data, fax, or video conferencing via satellite from different locations or remote sites to a central hub which could be the onshore support centers from which data can also be transmitted back to the respective sites through satellite and also Use of smart video –based online communication technologies e.g. Visi-Wear such that online collaboration and interaction is made possible between the offshore crew and operators, engineering contractors, remotely located CBM experts and asset team.(Liyanage et al, 2009)
- Availability and utilization of open standards or standardized protocols to enable system interface for exchange and interoperability.
- Competency development and re-training of personnel

But the fundamental criteria for e-operation-e-maintenance approach lies in the synergy between the use of advanced CBM technologies for diagnosis and prognosis of offshore equipments, the presence of an onshore support center linking the offshore expert centers through net and finally web-based ICT solutions enabling collaboration and access to the offshore facility.

7.1 REMOTE SUPPORT CENTERS (OSC)-THE BP\VRD

The British Petroleum Valhall project is the largest redevelopment program currently running in the North Sea. The project involves introducing a new production platform (PH) and taking the existing production platform (PCP) offline by bypassing the PCP and connecting to the new processing facilities to the existing facilities in the bridge connected Valhall complex field which are the drilling platform (DP), wellhead platform (WP), water injection platform (IP) and the flank platforms north and south of the field. Upon completion, there will be over four hundred meters of bridges and walkways, three new support towers and many, many hundreds of meters of integration pipe work, cables and tie in. The prerequisite for the success of the BP Valhall project towards adopting the IO concept lies not only in the use of advanced technologies but in the CBM-enabling technologies i.e. the protocols such as WSN and the accompanying standards able to provide the necessary data interface capacity and transfer of condition monitoring data from onshore to the offshore platforms.

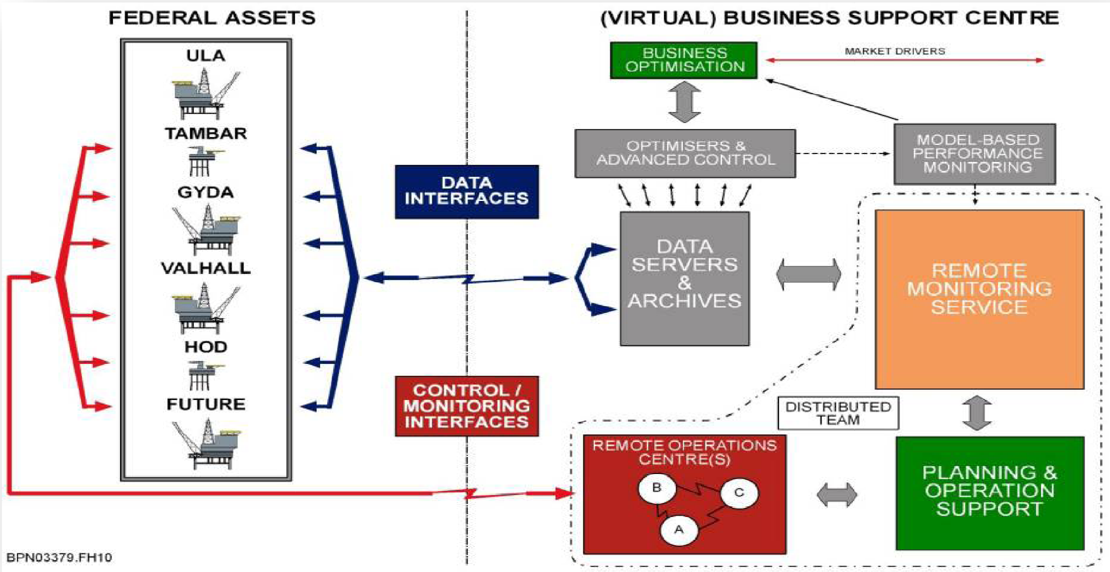


Fig. 23.0: IO Architecture for BP facilities (Stornes, n.d.)

IO architecture of the BP Valhall is such that it is connected along with other BP platforms to the BP office in Stavanger through the use of fiber optics. The Stavanger office acts as an onshore base for some maintenance vendors though SKF operates its own onshore support center for BP facilities. It has already adopted remote monitoring for its turbines, compressors, pipelines etc and is currently in the OLF Generation 1 phase. Expert centers are now equipped with advanced technologies capable of achieving e-operational objectives such as the use of advanced data acquisition techniques through which data can be gotten in real time from the offshore facility, the ability to communicate online with the offshore expert centers to enable joint interpretation of monitoring results, logistic assistance and trend analysis and the ability to monitor and offer 24\7 online services to operators on different platforms simultaneously. There is the availability of communication technologies to offer live services through video conferencing to the BP offshore personnel without having to be present onsite. Such connectivity and interactivity enhances efficient coordinated planning and execution of operation and maintenance activities and effective decision loops (Liyanage, 2009).The IO objective as regards to onshore support center for BP Valhall project is to establish one integrated operation team independent of location.(Stornes, n.d.).The SKF remote center acts as the health management facility for BP Valhall platform where it is able to remotely monitor its critical and essential equipment and offer diagnostic and prognostic services

THE SKF Onshore Support center

The SKF support center is located onshore at the Stavanger office where it is able offer its services to its customers in the Danish and Norwegian oil and gas regions. From this center it has been able to carrry out a variety of services from online remote vibration monitoring of critical machineries offshore ranging from compressors,turbines,pumps etc, logistics assistance,root cause analysis, and proffer solutions to machine and component failures.The center is equipped with collaborative facilities through which clients can communicate in real time with the experts at the SKF center.These facilities range from large video display units(VDUs),video conferencing facilities,supportive technologies to produce 3D images and run simulations.With recent introduction of wireless systems such as sensors and the Multilog online protection and monitoring system(WMx) and other products,SKF has been able to monitor,collect and analyze data from machines or bearings after which the report or information is sent through web-enabled or wireless access to a central information which is the SOIL through which the operator and other contractors can have access to the information.
Other OSCs such as the ConocoPhillips are in operation and serve as the ideal support centers towards e-operation and maintenance.

7.2 VENDOR STANDARDIZATION WITH RESPECT TO INTEGRATED OPERATIONS-OPEN STANDARDS FOR THE BP-VRD AND GOLIAT PROJECTS.

Without the presence of standardized protocols, interoperability and exchange of data would be extremely difficult. Most vendors and automation companies use propriety protocols for their systems due to competitions thus limiting accessibility. Therefore it is necessary for all the stakeholders to adopt a standardized protocol for the e-operations process which will apart from enabling interoperability and exchange would also

- Reduce the risk of obsolescence such that the standards permit use for new applications or technologies
- A good enabler toward competency development since it is easy to comprehend by the operator and maintenance personnel.
- Cheaper and quicker updates, technology insertion and increased operational availability through greater flexibility in repair and upgrade.

In high North projects like the Goliat field which is environmentally sensitive, remote application technologies are the most probable solution and thus a demand for heavily instrumented facilities and automated work process which would require high demands for communication and information flow.

Fig: 24.0: Integrated Operations in the High North (OLF, 2006)

The OLF Generation 2 solution would be most suited for the Goliat project and would require a common ontology with well defined concepts or which the extensible Markup Language (XML) tags are defined together with definition of rules, relations and properties specified in the Reference Data Library (RDL).The XML is an open protocol designed to transport and store data therefore vibration data from the various sensors on the equipments would be transported in form of XML schemas to an integrated CBM portal displaying all the data on a common domain.(OLF, 2006). For the VRD project which is currently operating in the Generation 1 phase and the Goliat project, the need to adopt the following standards for data integration is necessary. For integration and interoperability of data between the various parties involved the following standards are deemed necessary.

7.2.1 POSC CAESAR ASSOCIATION (PCA)-ISO 15926

POSC Caesar Association (PCA) has through the ISO TC 184/SC4 already developed a methodology for data integration across disciplines and phases which was documented in ISO 15926 and as such will be used as a starting point. Thus PCA in collaboration with the OLF is developing an oil and gas ontology for integrated operations on the Norwegian Continental Shelf to be able to establish a real time information platform that will be able to support the generation1 (G1) and generation 2(G2) IO stages. To achieve this, the Independent Information Platform (IIP) project was established under the support of the Norwegian Research Council and is expected to meet such task by developing.

- Machine-interpretable terminologies and XML schemas for consistent transfer of data between applications in same domain .These are documented in the POSC Caesar reference data library (Accessible at: http://www.posccaesar.org/wiki/Rds).
- Taxonomies facilitating combination of data across domains
- Complete ontologies supporting automated reasoning or inference of data using logical rules which be most suited for the OLF G2 phase e.g. the Goliat project.
- A Reference Data Library (RDL) containing terminologies, taxonomies and ontologies
- The basis for ISO approval of terminologies, taxonomies and ontologies.

The ISO 15926 standard is used as a starting point due to the fact that it is based on an ontology and first order logic i.e. a hierarchical data structure containing concepts, relationships, properties and rules for a specific domain from which other concepts can be deduced and more so has a generic concept model that makes it ideal as an integration platform for other standards and also ideal for use by the Web Ontology Language (OWL).This integrated information platform will furthermore be enabled by integrating several industrial data and technical standards consisting of the MIMOSA Open O&M, ISO 13374 standard, and also by adding new terminologies to it. So it's a combination of the best-breed of standards to enable easy data exchange and interoperability on the NCS. A list of approximately 500 relevant terms and definitions were extracted from the standards ISO1925 - *Mechanical Vibration – Balancing – Vocabulary* and ISO2041 - *Vibration and shock – Vocabulary,* both referenced from the standard ISO 13374- *Condition monitoring and diagnostics of machines*. A prioritization of these terms and definitions where done and approximately 50 prioritized terms and definitions where added as classes to the ISO 15926 Reference Data Library (RDL).

The ISO 15926 standard consists of the semantic part and the syntax part. The standard is used to facilitate the integration of life-cycle data for process plants including oil & gas production facilities. It consists of seven parts from which the semantics consisting of the ontologies, taxonomies and terminologies will be developed i.e. the simple language which the vendors, operators and other stakeholders are able to comprehend. The seven parts contains the following:

ISO 15926

Part 1: Overview and fundamental principles
Part 2: Data Model
Part 3: Geometry and Topology
Part 4: Initial reference data
Part 5: Procedures for registration and maintenance of reference data
Part 6: Scope and representation of additional reference data
Part 7: Implementation methods for data exchange and integration

The ISO 15926-1 specifies a representation of information associated with the activities on the NCS which must support the information requirements of the industries for all the life cycle phases of the plant and also the sharing and integration of information amongst all the stakeholders involved during the lifecycle. The *ISO 15926-2* is the data model which defines the syntax (grammar) used to design the semantics, i.e. terminologies, taxonomies and ontologies that will simplify the medium through which the various parties will be able to understand, manage and share data amongst each other. The OLF has adopted the World Wide Web Consortium (W3C) standards like XML, RDF (Resource Description Framework), OWL (Web Ontology Language) and the EXPRESS (ISO) as a form of expressing these ontology since it suits current and future IT solutions. The *ISO 15926-4 to 6* simply indicates the use and definition of reference data for the process plants.

7.2.2 INTEGRATED INFORMATION STANDARD-THE OPEN O&M FRAMEWORK

The Open O&M framework is an enabler for both Integrated Operations, condition based operations (CBO), condition based maintenance (CBM), and collaborative asset lifecycle management (CALM) strategies (Maintenance technology, 2005).For the oil and gas industry to fully implement condition based e-operations within and outside its organization, it will require a widely accepted standard for O&M information capable of supporting an extensive integration of O&M information from its other collaborators and B2B partners. The emergence of the Open O&M Framework is due to recent development to provide the industry with the interoperability capability to openly and securely exchange operation and maintenance information. It is been developed under the auspices of MIMOSA with two industrial organizations, the OPC Foundation, and the ISA SP95 Committee and involves harmonizing the standards and specifications from the respective organizations to produce a single interface for both the manufacturers and their vendors to be able to exchange O&M data or information with any other control or information system for the purpose of not only providing a quality standard but at a low integration cost and distribution time.

The Machinery Information Management Open Systems Alliance (MIMOSA) is a non-profit organization and it uses the Open Systems Architecture for Enterprise Application Integration (OSA-EAI) which defines XML schemas for the exchange of maintenance information critical for implementing CBM and CBO such as condition based monitoring, asset based registry, and maintenance work and parts management thus is suitable for interfacing all types of physical asset resource management systems. The International Society of Automation (ISA) is also a non-profit organization whose standard is been accepted by the IEC and ISO as the joint-logo international standard IEC 62264.The ISA organization connects individuals and ideas in automation and control and forms the ISA's SP95 standards committee with sole responsibility for creating enterprise-control system integration standards to define the interface between control and enterprise functions. It provides a standard definition for the vertical exchange of manufacturing data between business and control systems as well as on-going work to define a manufacturing operations standard and consequently enable Open O&M information to be exchanged with manufacturing operations and the business systems and as such would be most suitable for materials and personnel management at logistics level (Liyanage et al, 2009).The open connectivity via open standards (OPC) Foundation on the other hand uses the OPC interface specifications as the de facto standard for exchanging data between different systems in the manufacturing industries. Adopting the OPC technology will enable the Open O&M framework to use the most popular method of communication at the control and manufacturing execution system level thereby reducing the amount of work required to adopt it. It also enables the use of state-of-the-art technologies such as web services and the ability to provide secure data exchange and the use of encapsulated data with extensible Markup Language (XML) (Maintenance Technology, 2005).

Therefore the collaboration effort will bring about integrating the MIMOSA and ISA-95 data exchange formats and use the OPC interface specifications as the medium to transport the information between the systems. Other set of interfaces have now been defined on the operation side and it includes the OPCXML & MIMOSA OSA-EAI (low level accessing of machine control system and data) and the ISA SP95, OPCXML & OSA-EAI (intermediate, plant level forecasting, planning and scheduling systems) and others for the enterprise system information network of which the OPC's client-server technology will be used to exchange OSE-EAI and ISA-95 format data as required by an enterprise's information needs. (Maintenance Technology, 2005) as illustrated below:

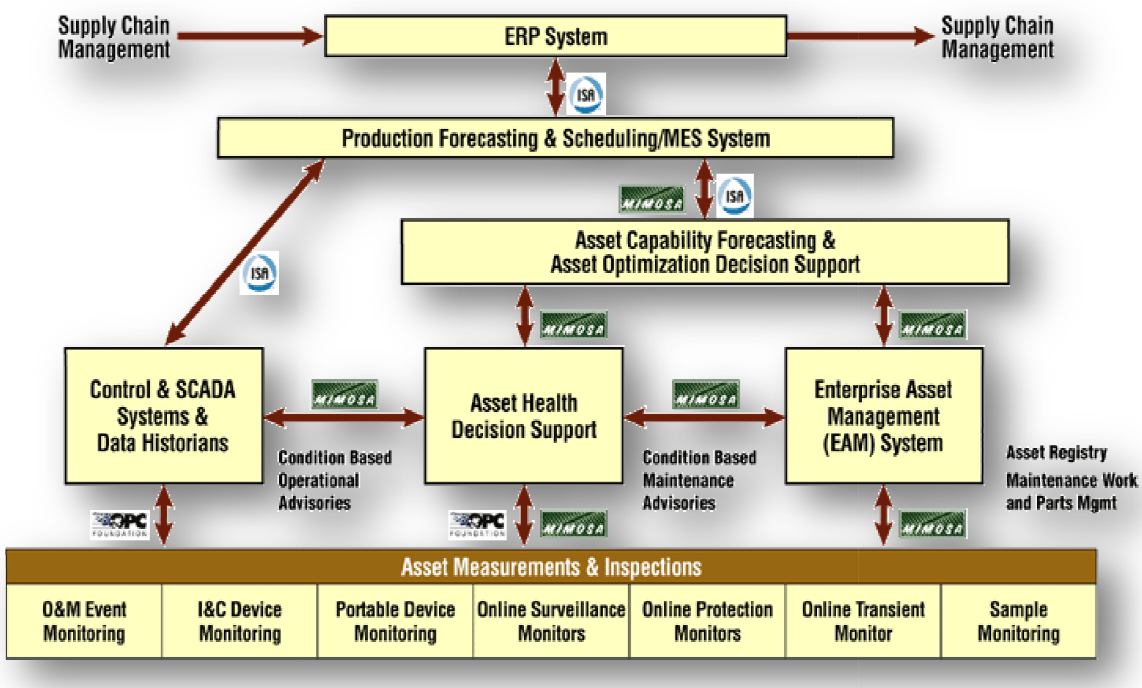


Fig.25.0: Enterprise System Information Network (Maintenance Technology, 2005)

Furthermore, without a generally accepted standard for operation and maintenance information, adopting a condition based system of operation would lead to a complex system or structure of information integration as a result of the development of numerous point-to-point interfaces as illustrated in the figure below which will be time consuming and relatively costly.

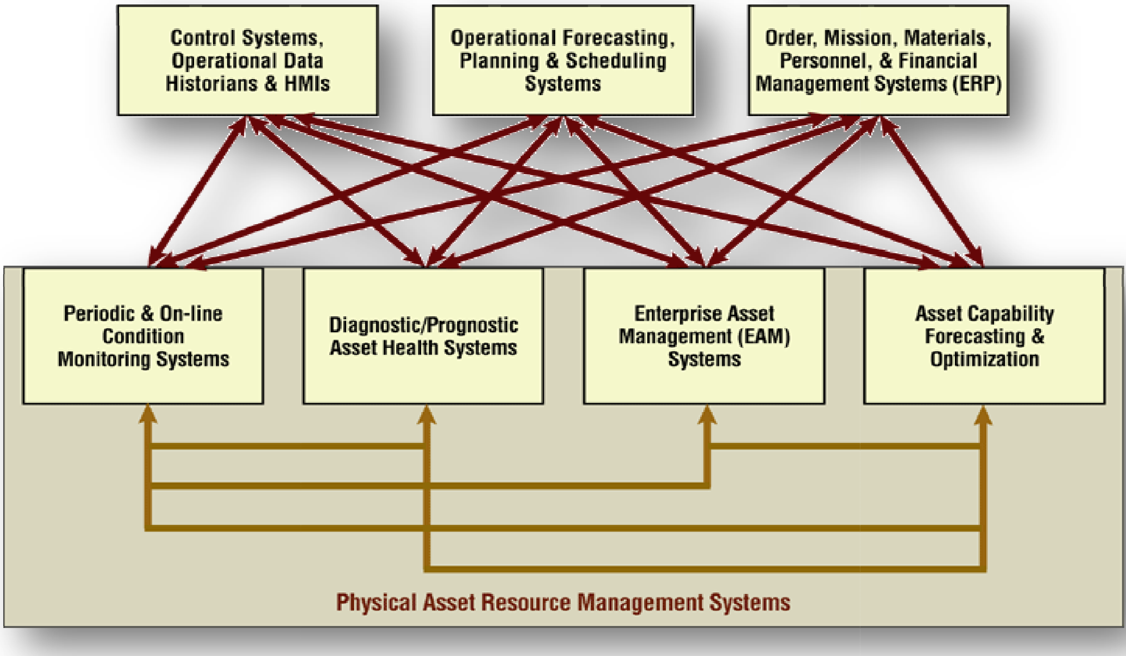


Fig. 25.1: A complex communication structure without the Open O&M Standard (Maintenance Technology, 2005)

However, the adoption of the Open O&M Framework will enable third party participation from vendors, manufacturing and operating companies, suppliers and logistic companies etc to develop a single interface for each system to be able to exchange operation and maintenance information at low integration cost and in due time. The figure below shows the set of interface standards developed for such operations which is highly effective and efficient for e-operations for present and future industries.

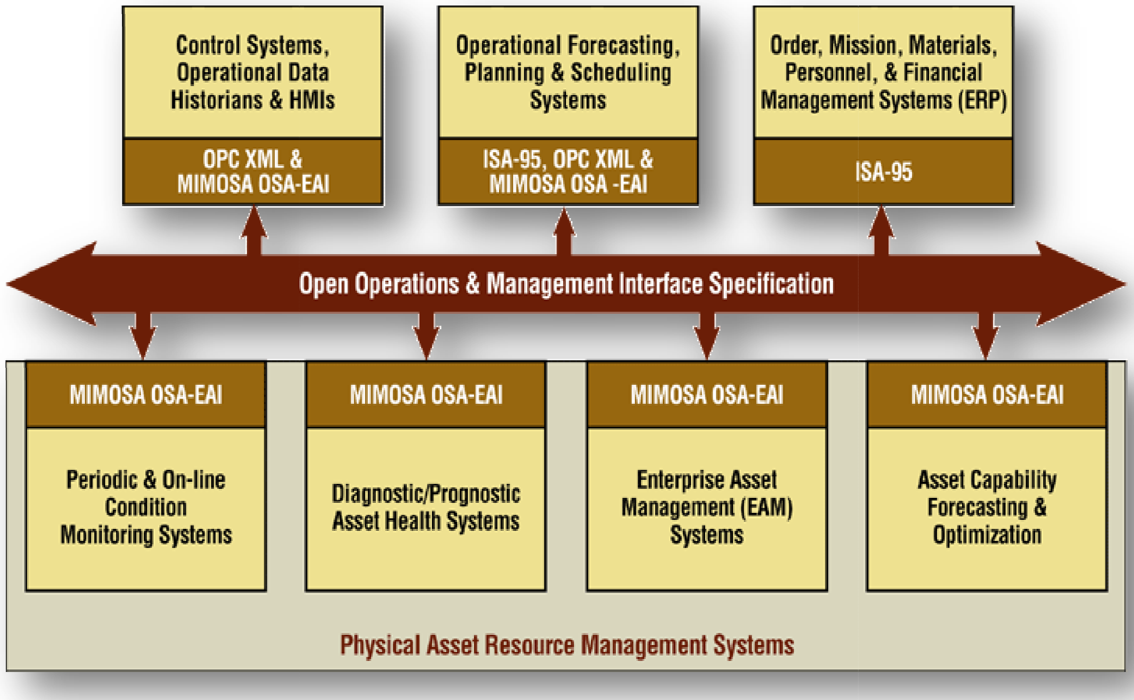


Fig. 25.2: A Single interface communication structure with the Open O&M Standard (Maintenance Technology, 2005)

7.2.3 CHALLENGES USING THE MIMOSA OPEN O&M FRAMEWORK

The MIMOSA Open O&M standard will definitely face some major challenges and hurdles in today's industry but the speed of adoption of these standards would most probably rely on the end-user organizations or operating companies to mandate their vendors and business partners to the adopt the standards for integrating their O&M systems, a move now been adopted by the US department of defense for its military operations. (Bever, 2006).Also necessary is the need for technical inputs from the end-users concerning the standards. Therefore since it is a win-win situation for all the parties involved, the tendency of not adopting these standards is low and will most definitely achieve a remarkable success for the future of e-maintenance and operations. The likely major challenges to be faced would be acceptance, education and expansion i.e. getting both the end-users, vendors and others to adopt a common standard, educating the end-users, integrators and vendors on how to utilize these standards for their respective projects and the need to expand the organization to include other supplier, integrator and automation organizations such that a widely accepted standard is formulated by adopting from the numerous open standards which at present poses serious 'selection challenges' for the end-users. Through the open O&M Initiative they have been able to encourage other appropriate organizations to join and currently present in the committee are the ISA

(SP-95 and SP-88), OPC Foundation, Open Applications Group (OAGi), and World Batch Forum (WBF).
Other organizations like the Organization for the Advancement of Structured Information Standards (OASIS) which presently produces more web standards than most standard organizations are in the fore front of also developing, promoting and encouraging the adoption of open standards.

Other probable challenges have to do with the business implications and technical challenges involved such as:

- The presence of extremely complex platforms with many components.
- Handling voluminous data with not enough shared information and knowledge between the parties pose a serious challenge. Since it's all about business most vendors would rather grant access to raw data than providing access to the relevant information.
- Vendors trying to promote their own propriety data standard as the optimal standard for a specific application since it is normal that both the end-users\operators, vendors etc all have competing interest.
- The presence of multiple data languages and having multiple data formats from a variety of systems would pose a challenge.
- The tendency for one-way operability.
- Big vendors with large installation bases are faced with high cost of switching and as such will be unwilling to adopt the standards.

7.2.4 OTHER RELEVANT STANDARDS-ISO 13374 AND WIRELESS HART STANDARD

Other relevant standards include the ISO 13374.The ISO 13374 is a published standard for open software specifications which will allow machine condition monitoring data and information to be processed, communicated and displayed by various software packages without platform-specific, vendor-specific, or hardware-specific protocols. This standard consists of six functional blocks for condition based maintenance i.e. Data Acquisition (DA), Data Manipulation (DM), State Detection (SD), Health Assessment (HA), Prognostics Assessment (PA), and Advisory Generation (AG).Its two parts ISO 13374-1 and ISO 13374-2 provides reference to the open, vendor-neutral, XML-based consensus standards and only the MIMOSA OSA-EAI and OSA-CBM Specifications are compliant to this standard. (Bever, 2008)

For the automation vendors such as ABB, the release of the wirelessHART standard(based on the 802.15.4 standard) will enable them to face challenges with regards to WSN enabling them to co-exist with typical offshore systems and other sensor networks such as WLAN which is been widely used to avoid disruptions in data exchange. The wirelessHART was developed to support applications such as field device troubleshooting, device status and diagnostic monitoring, critical data monitoring with more strict performance requirements, supervisory process control, and calibration and commissioning. According to Birkemoe et al (2008) other emerging standards for industrial applications include the ISA 100 which has a larger application than the wirelessHART and covers other standards used for process automation (ISA100.11a), factory automation (discrete focus), transmission and distribution (long distance focus) and RFID (industrial tagging focus).Furthermore there is an ongoing discussion by automation vendors to integrate both the wirelessHART and the ISA 100 standards to ensure interoperability and data exchange.

7.3 DIGITAL IT AND COMMUNICATION INFRASTRUCTURE

Therefore the use of wireless sensor networks is highly recommended for offshore platforms which consist of numerous equipments ranging from fans, pumps, motor-driven equipments requiring steady maintenance. Its benefit is not only due to its low cost but it's a highly reliable communication network suitable even in the harshest environment such as the Golait project and has a major advantage when it comes to feeding measurement and communication equipment data to central units such as the SOIL (Birkemoe et al, 2008).

The secure oil information link (SOIL) is an ICT network introduced first in Norway in 1998 by OilCamp, a leading global provider of collaborative communication services for the upstream oil and gas industry. It addresses the demand for an integrated data management and B2B communication. The SOIL acts as the oil and gas industry own extranet through which interconnectivity and interactivity is established between the various stakeholders through the use of fiber-optic cables or wireless communication such as the wirelessHART discussed above. This digital communication infrastructure through the use of web solutions enables one-to-many or many-to-many connectivity which encourages simultaneous interaction between the asset operators, expert centers, logistics contractor and even access to the industrial assets, both the mobile and offshore platforms, this service is currently extended to the UK and Houston, Texas offshore industries. Furthermore, the enhanced collaborative services the SOIL provides is through the use of RigCamp which has application services such as the SOIL meeting which enables the contractors, O&G producers and supply companies to able to communicate with each other with the use of teleconferencing or videoconferencing tools. It also has the SOIL directory which contains information on member companies and employees whereby faster access to specific competences or services which can easily be outsourced. Other key application services include the E2E monitoring which supplies the operators with real time data or information on the current status of the equipments and the Proex,a web-based solution which assists in structuring, defining, executing and following up various tasks and activities in work processes and project.(Liyanage et al, 2009).

The preference for SOIL over other IT facilities such as the Internet or VSAT is that it:

- Updates with the latest service and technology such as collaborative tools, equipments etc. So the user doesn’t have to specify who to connect to, pay for any changes or have to wait until such changes take effect.
- Has no bandwidths limits therefore it is able to support a wide range of bandwidth applications which is always available and accessible thus speeding up internal work processes and productivity. It is known to have an average uptime of 99.97% (Oil Camp, 2009)
- The SOIL is an extremely reliable and secure network for transfer of data meant for the oil and gas industry only.
- It is cost effective such that there are no charges for new members joining the network and requires only a monthly subscription to enable communication with partners, suppliers and other business associates.

7.4 COMPETENCY DEVELOPMENT

Integration of work processes, transfer of functions onshore and new possibilities for suppliers of condition monitoring equipments or services would require new competency development for both the condition monitoring vendors and operators with the onshore centers needing the most competent personnel. Therefore such need would require employees with high technology status and specialists fields. Automation and condition monitoring vendors would require specialist skills in systems engineering, artificial intelligence, process automation, smart systems development etc and other specialist fields which would be IO related. There would be a need for re-training of staffs imbibing them with interpersonal skills and other requisite skills required for staffs to work as a team rather than individual contributions. The parallel and complex nature of the entire work process is such that different task could be done at the same time which would require people working in teams will increase the demand for social and meta competences such that they are able to work in teams. Team work is currently seen as a characteristic feature required for most jobs in the oil and gas industry and as such is a step in the right direction towards e-operations and e-maintenance for both the Generation 1 and 2 phase such that the monitoring experts and operators are able to collaborate both in a virtual center through telecommunication methods or in the event of the generation 2 phase where experts from different organizations are working together in the onshore support centers.

Therefore from the interaction between the various stakeholders consisting of the maintenance experts, the logistics personnel, and suppliers etc the tendency to develop interdisciplinary knowledge is inevitable and as such would lead to an increase in demand for cognitive competence as a result of the interdisciplinary work process. To enhance multidisciplinary skills for its workforce, job rotation should be encouraged so personnel are able to get an overview of virtually every function in the work place.

Furthermore the introduction of advanced tools and technologies would not only be used during e-operational activities but also for training of staff which could be on-the job training with the use of simulation techniques and tools and as such would also demand functional skills and practical knowledge of information and communication technology (ICT).Thus it is necessary for personnel to exhibit flexibility because as new technologies are been introduced, new work processes have to be developed.
The type of competence that would be required of both individual and professional activity with regards to e-operations has been specified and can be grouped into two major categories:

- Competences related to professional activities and
- Competences based on individual abilities

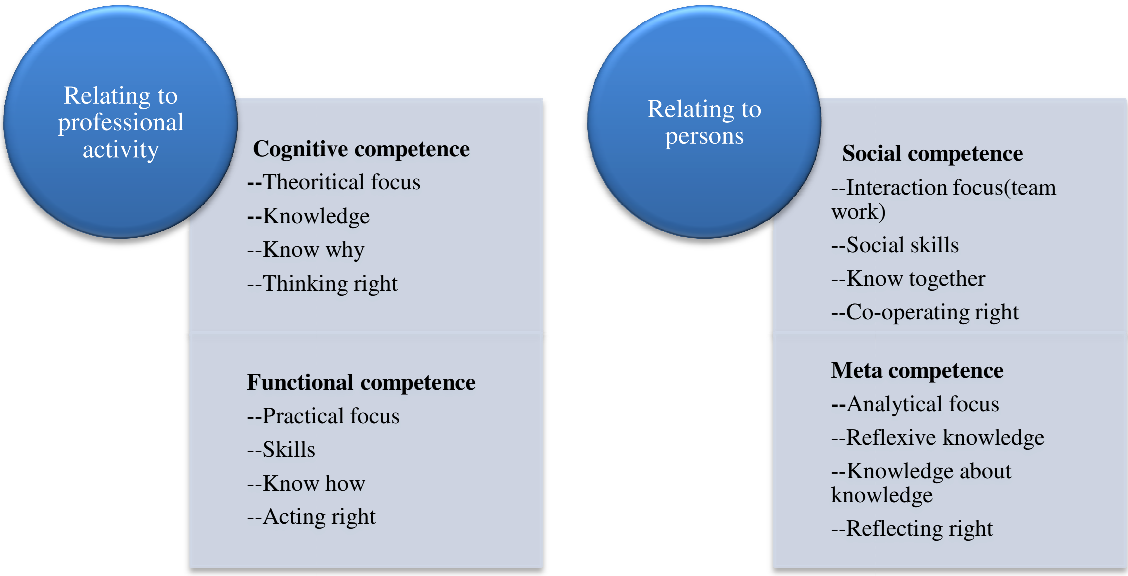


Fig. 26.0: Types of Competences (Fjærtoft, 2006)

Therefore vendors, automation and instrumentation suppliers have a major role to play in this regard by either encouraging the development of technical and ICT-based subjects through affiliations with the various universities by creating opportunities for programs such as internships, seminars to educate and expose students to real time scenarios such as video conferencing, real time monitoring and use of collaboration tools for e-maintenance. Also these industries could also establish Integrated Operation centers either in collaboration with the institution such as the NTNU IO center or between the various partners where learning and further research into ways of improving e-maintenance. Fundamental research areas will not only involve building of the requisite competence but also should include work processes development, virtual team training and other technical challenges such as standards, enabling software and hardware etc.

CONCLUSION

The market for condition monitoring equipment and technology is a huge one with great potential for future expansion and exploitation in both the service and product segment of the market. With more expansion and market opportunities for the service segment due to outsourcing, the product segment has also created a suitable market for manufacturers of critical and non-critical equipment. With the latter being used as sustenance strategy for smaller vendors in the condition monitoring markets where there is more R &D into e-monitoring of smaller equipment. From the survey conducted, recent condition monitoring equipment and technology are been developed with the focus of exhibiting smart or intelligent autonomous capabilities of supporting maintenance decisions, analyzing data with enabling wireless access through which data and information can be conveyed from one point to another independent of location, a positive trend towards implementing e-operations and e-maintenance. This trend is revolutionizing the various industries and will likely promote the use and general acceptance of advanced condition based monitoring techniques or e-maintenance in these industries. It will further open up more business opportunities for condition monitoring vendors both in terms of developing innovative application technologies or supplying condition based maintenance services which was previously limited to O & M but would now involve them taking part in e-operational projects from feasibility phase to even decommissioning. This signifies an even share of both the risks and gains in such projects between the vendors and its clients and further involvement in these various phases would open up new roles and responsibilities for condition monitoring vendors which would require retraining of personnel and the need for new competencies.

However an inevitable point of concern lies in both establishing a common technical language to enable the successful implementation of condition monitoring in integrated operations and convincing the vendors to accept this technical language so as to enable data access and information flow between the various stakeholders responsible for O & M activities. Remarkable progress has been made towards achieving this where condition monitoring data is been exchanged between four major leaders in the condition monitoring industry but one thing remain certain information security would also play a vital role towards the general acceptance of a common technical language. Other salient keys to unlocking the full potential of such a profitable enterprise would be the establishment of support centers onshore where integrated planning and O &M activities can be conducted and the use of an efficient ICT infrastructure such as SOIL capable of enhancing collaborations between the stakeholders and achieving other suitable integrated operational needs of the project.

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APPENDIX

1. 0 **Table 4.0: Unit shipment and revenue of world condition monitoring equipments**

Year	2005	2006	2007	2008
Unit shipments	43,700	48,000	52,900	58,400
Revenue($millions)	472.6	521.0	577.0	640.5

2.0 **Table 5.0: Unit shipment of condition monitoring equipments and services (%)**

YEAR	2002	2009
Vibration monitoring equipment	74.5	76.8
Oil analysis equipment	7.4	6.9
Thermography equipment	5.6	6.0
Corrosion monitoring equipment	12.5	10.3

N\B: Reference Source: (Frost and Sullivan reports, 2008)