Process optimization through integration of control and asset management

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ABSTRACT

This research work focuses on the use of integrated control and asset management (ICAM) in optimizing process plant operations. The assets considered are mainly valves and instruments, such as pressure, flow, temperature and level transmitters.

The dissertation discusses how integrated control and asset management could be used to detect potential process problems as well as incipient faults in field devices and valves.

Integrated control and asset management is a technology whereby the control loop or system is made to perform functions other than its traditional function of controlling the process in order to achieve an improved production target.

The conditions of the instruments, valves and the process itself are monitored with the aid of another system called asset management. The condition monitoring data is superimposed on the process control signal thus giving the name 'integrated'. Commonly known as artificial intelligent design, the asset management software is able to unlock data buried in a distributed control system (DCS), supervisory control and digital acquisition (SCADA), programmable logic control (PLC) or other remote terminal units (RTUs), analyze it and give actionable recommendations.

Two plants in Sasol which have deployed the ICAM technology were investigated namely the Auto-Thermal reforming (ATR) plant and the N-Butanol plant. The research investigation revealed that the use of ICAM gives rise to

i) a proactive maintenance strategy
ii) increased uptime which means reduced downtime
iii) increased throughput
iv) removal of unnecessary maintenance of valves and instruments and
v) an improved way of running the process.

The ICAM technology has been made possible by the HART technology, the foundation fieldbus technology as well as SMART-based instruments and valves. Some limitations of ICAM were also discovered as well as other factors that could hamper it from delivering its full benefits.

DEDICATION

...to the evergreen memory of my later father chief Ebenezer Oluwole Akintunde who slept in the LORD on the 30th of October, 2004.

ACKNOWLEDGEMENT

Perhaps this research would not have been possible without the grace of the Almighty God, the father of lights. I am grateful to you, LORD.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Generally, plant equipment (whether electrical, mechanical, process or instruments) are one of the major assets of any process industry. Processes do not operate in isolation; the different pieces of equipment make them happen.

The greatest investment in any plant is, arguably, on equipment. It is therefore logical and reasonable to give the greatest attention possible to the health and integrity of equipment that make up a process plant.

Equipment failure can have serious consequences, even to the extent of plant shutdown, with all the losses that go with this. One major consequence of equipment malfunction is sub-optimal plant operation. A huge amount of money could be lost due to unforeseen equipment failure.

A new technology is emerging whereby imminent equipment failure can be detected. Corrective actions can thus be implemented before failure occurs. The success of this technology lies in the fact that it integrates the plant control with asset management functions. This integration is not possible in orthodox valves and instrumentation because they are not intelligent, thus limiting their usefulness in ICAM implementation.

By integrating asset management functionalities with the control system, effective tracking and management of the health of field and process-based assets, and control loops can be achieved. This is because valuable data that could be used to assess the health condition of an asset and spot potential problems is imbedded in control equipment such as remote terminal units (RTUs), programmable logic controllers (PLCs), supervisory control and data acquisition (SCADA) systems and distributed control system (DCS).

Besides, valuable data also resides in manually maintained Excel spreadsheets, paper reports, or applications that require manual entry.

The potential of using ICAM in plant process operations is enormous, ranging from cost savings and profit maximization to operational excellence.

Incorporating a computerized system that takes data from the DCS or SCADA, process it and convert it to actionable recommendations will bring about

a) improved equipment reliability
b) minimized downtime through early detection of faults
c) maximized component life by avoiding the conditions that reduce equipment life and
d) maximized equipment performance and throughput.

Also,

- Diagnostic capabilities will be more improved and sensitive.
- Maintenance decisions will be more informed.
- Process operations will be more optimal.
- In fact, equipment lifecycle can be extended beyond the manufacturer's benchmark.

Olsen et al (2006) posited that *"process optimization should always include an evaluation of the field devices and an optimization of their performance. Hardware issues primarily include the control valve performance, but transmitters, pumps, and other field devices can also contribute to poor process performance. With poor performing field devices, the control loop is usually de-tuned to maintain controller stability. The unit is stable, but process performance and potential economic benefits are lost."*

1.1.1 Why Asset Management?

Asset management is a broad term with varied interpretations. Some definitions which are congruous to the context in which it is used in this work are presented below

i) Asset management is defined as a global management process through which we consistently make and execute the highest value decisions about the use and care of our assets (Peterson, 2006)

ii) Asset management as defined in a recommendation [NAMUR NE91] means activities and steps designed to maintain or enhance the value of a plant or facility (Becker et al, 2006:5). It includes operations management, process optimization, as well as value-maintaining, and where possible, value-increasing maintenance.

iii) Used in the plant context, asset management seems to imply a broader view of the plant asset than solely maintenance and reliability. Other concepts spring to mind: suitability to purpose, the business value of the maintenance activities, the competition within the plant for scarce resources, and lifecycle valuation for equipment. Its goal is to "completely align plant resources to achieve the business goals of the organization at the lowest cost." (Peterson, 2005:1)

From the definitions above, it can be observed that the objective of asset management is to maintain and enhance the value of plant assets. That is, to ensure that the existing equipment is being used to its fullest advantage by

- looking at the operating data to determine the equipment bottlenecks and
- being proactive in maintenance

According to Reeves (2006:2), '*by comparing a unit's machinery health value with such process values as pressure, temperature and flow rate, an operator or control engineer can begin to see how changing process conditions can affect a machine's health*'.

Asset management is thus an essential component for organizations to derive maximum benefits from minimum investment in plant and equipment.

By integrating asset management with the control system, therefore, instruments and valves health monitoring can be reliably achieved. Besides, the process conditions that degrade them can be made known.

1.2 PROBLEM STATEMENT AND SUBSTANTIATION

Integrated control and asset management is a relatively new phenomenon. It started gaining ground only in the early years of the twenty-first century. As such, companies are somewhat skeptical in investing in this technology due to insufficient evidence of its success. In South Africa, for example, case studies of success in integrated control and asset management implementation are scant.

While remarkable success has been recorded in the asset management of other plant assets such as electric motors, pumps, compressors etc. little has been done in the area of field devices, namely instrument sensors, transmitters and valves. With the technology of integrated control and asset management (ICAM) now emerging, and coupled with the great promises it allegedly offers, it is proper to conduct research on two leading plants in Sasol namely the N-Butanol plant and the Auto-thermal reforming (ATR) plant with a view to quantifying the benefits of investments in integrated control and asset management.

Besides, most of the claims made regarding success in integrated control and asset management did not originate from a scientific inquiry. In fact, some plant managers think that these claims are being used for marketing purposes because they are propagated mainly by the vendors of this technology. It is therefore worthwhile to investigate in a scientific manner and from a detached point of view the potentials of this technology vis-à-vis the experience of the plants which are using it in Sasol.

In other words, does ICAM truly offer optimized process operation in these plants? How is this achieved? Is the return on investment, if any, worth the effort? Can Sasol's operation in these plants now be regarded as world class? These are questions that this research seeks to investigate.

1.3 RESEARCH OBJECTIVES

This research work is being prosecuted with a view to

1. quantifying the monetary and non-monetary benefits of integrated control and asset management in two leading Sasol plants

2. determining to what extent field asset performance is enhanced by using integrated control and asset management technology

In addition, the work is aimed at verifying that by implementing integrated control and asset management technology, the running of process plants can be optimized, uptime increased and unforeseen equipment failures minimized.

1.4 BENEFICIARIES

Verifiable evidence that integrated control and asset management offers optimized process operation will foster greater confidence in investing in leading edge technologies that will empower an organization in achieving its business objectives.

Besides, early detection of incipient faults through asset management can trigger work orders in an integrated computerized maintenance management system (CMMS) well in advance of a failure. As a result, labour, work instructions and parts can be allocated and coordinated between maintenance and production organizations, thereby avoiding unplanned downtime, production losses and unnecessary overtime expenses. The chief beneficiaries include

- Plant Managers
- Operations Managers
- Instrument engineers and technicians
- Maintenance personnel
- Plant operators

In the chapters that follow, the concept, philosophy, design, findings as well as the recommendations and conclusions of this research work are presented.

Chapter two deals with the literature review vis-à-vis integrated control and asset management or simply asset management. There, the work of various researchers, authors and experts in integrated control and asset management is presented and a critical appraisal of their views and conclusions in relation to this research work given. The papers and books were chosen to cover the underlying principles and techniques of asset optimization and maintenance related issues of asset management. Also, important terms and concepts vis-à-vis integrated asset management and control are discussed.

In chapter three, the research design is presented. To achieve the stated objectives, the N-butanol plant and the ATR plant in Sasol One and Midland sites were investigated. These plants were chosen as case studies of practical implementation of integrated control and asset management. The modes of empirical investigation into the subject matter such as observations, surveys (mainly interviews), case studies etc as they relate to the research objectives are discussed.

Chapter four focuses on analysis of results and discussions on the findings in chapter three while chapter five articulates other success stories of integrated control and asset management in other parts of the world with a view to benchmarking the findings of this research work as presented in chapter four.

Chapter six concludes the research work with recommendations and conclusions.

CHAPTER TWO

2.0 LITERATURE REVIEW

In this chapter, a review of technical papers on this subject matter is presented. But before then, a brief description of some key terms and concepts will be considered.

2.1 Optimization in the Process Plant

White (2003:1) defined optimization as 'the general technique for determining the best set of decisions within the constraints imposed that maximize or minimize the specific result desired'.

In its most general meaning, optimization refers to the efforts and processes of making a decision, a design, or a system as perfect, effective, or functional as possible. It encompasses specific methodology, techniques, and procedures used to decide on the one specific solution in a defined set of alternatives that will satisfy a selected criterion. (Parker, 1984:1215)

In the past, the principal objective of optimization was to maximize product value and minimize raw material cost. This is normally done using a priori knowledge where we know there are optimization targets, such as minimizing or maximizing of one of the production parameters (i.e. the objective function) within constraints on process inputs.

Today, plant optimization has taken a higher dimension. Now, it encompasses the enhancement of performance at minimal cost on all assets that make up a production facility. Besides, the requirements for higher safety standards have defined a new perspective in the way organizations optimize their operations. The focus is not just on higher production yields, but production at higher standards of safety.

To achieve a holistic optimization of all assets in a production plant, the strategic asset management Inc. (SAMI) developed a model which has become a world class best practice.

2.1.1 The SAMI model

The SAMI model below (Fig 1) captures the length and breadth of asset management at the macro or enterprise level. It is a holistic approach to asset management. Operational excellence (Stage 5) is where every company strives to attain but there are ladders that must be climbed in order to attain this level.

Stage 1 deals with the work management system or planning of maintenance works. Planned work has been found to be three times more efficient than unplanned work. Stage 2 (Proactive maintenance) is where integrated control and asset management finds direct relevance.
By employing condition monitoring and predictive techniques, failure events are reduced. Failure prediction is accomplished by using equipment history to identify time-based failures. Through a consistent program of failure analysis, failure modes are eliminated or mitigated.

Integrated control and asset management does not exist in isolation. It fits well into the SAMI asset management model. In fact, higher stages would not be a reality without a successful and sustained implementation of stage 2.

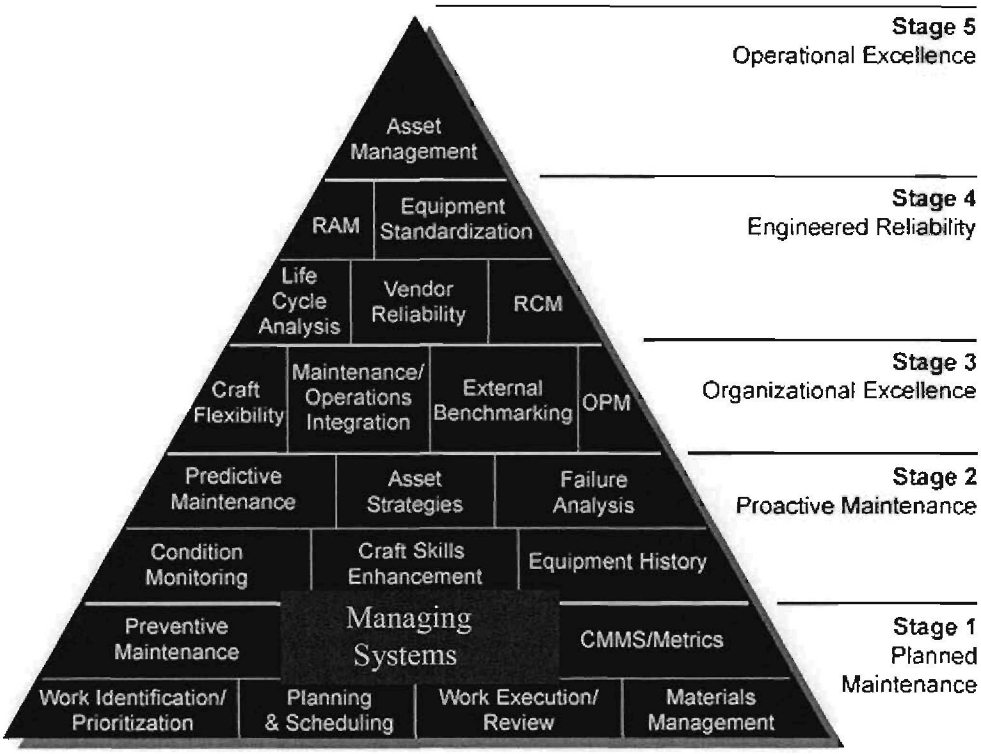

Figure 1: The SAMI pyramid model (SAMI Model, 2006)

In other words, stage 2 (proactive maintenance) is the pivot upon which the effective implementation of higher and lower stages is hinged. This makes integrated control and asset management a veritable tool in achieving operational excellence.

To achieve a holistic optimization of the process plant operation, all of the components that make up the plant, i.e. the chemical/physical process itself, the equipment, the operating procedure, the control system, and the work processes that interface with all of these, must be optimized. Nonetheless, the focus in this work will be on instrumentation, which includes valves.

2.1.2 Process Optimization

Process optimization is the practice of making changes or adjustments to a process by use of specific techniques to determine the most cost effective and efficient solution to a problem or design for a process. (Wikipedia, 2006)

By 'process', we mean any system where material and energy streams are made to interact and to transform each other. Examples are the generation of steam in a boiler; the separation of crude oil by fractional distillation into gas, gasoline, gas-oil and residue; the sintering of iron ore particles into pellets; the auto-thermal reforming of natural gas (composed mainly of methane) into synthesis gas; and the polymerization of propylene molecules for the manufacture of polypropylene. (Parker, 1984:1391)

Optimization of the core process area is left to experts in this field. So, core process optimization is not the focus in this thesis.

2.1.3 Equipment Optimization

Processes do not operate in isolation; equipment make them happen. So, we will be optimizing the plant (for example, increasing throughput) by decreasing downtime when the equipment themselves are optimized.

Berra (2003:1) stated that *"while traditional maintenance is reactive, asset optimization is proactive."*

Asset optimization recognizes that assets – from mechanical, electrical, and process equipment, to instruments, valves, and process automation systems – have a huge impact on uptime, throughput, product quality, and production costs. When the assets perform well, the return goes up. In an attempt to optimize asset performance, the paradigm is shifting from reactive to proactive maintenance; and from preventive to predictive maintenance.

Several Equipment Optimization strategies have been developed and the applicable strategy varies from equipment to equipment. One strategy upon which asset management is predicated is condition monitoring or condition-based maintenance. But it is more than condition-based maintenance. The aim of condition-based maintenance is to reduce direct maintenance expenses by identifying impending failures early enough to avoid costly repairs and reducing downtime. Thus, maintenance is only performed when required.

Asset management further builds on this by finding the optimal balance between the needs of the process and the needs of the assets to achieve the business objectives of safety, quality, and profitability. In fact, the useful life of an asset can be prolonged beyond the manufacturer's benchmark.

Because condition monitoring or condition-based maintenance plays a crucial role in asset management, a brief description of condition monitoring and the seven layers that make up the system is presented below. Thereafter, a review of technical papers will be presented.

2.2 Condition Monitoring/Condition-Based Maintenance

This research work focuses on equipment (instruments and valves) optimization; condition monitoring or condition-based maintenance forms the basis upon which this is predicated.

Condition-based maintenance (CBM) is 'maintenance actions based on actual condition (objective evidence of need) obtained from in-situ, non-invasive tests, operating and condition measurement'. (Mitchel, 1998:1)

According to Kelly et al (2003:2) "condition-based maintenance (CBM) is maintenance carried out in response to a significant deterioration in a unit as indicated by a change in the monitored parameters of the unit's condition or performance."

Moya et al (2003:2) argued that the purpose of a CBM program is to 'improve system reliability and availabile product quality, security, best programming of maintenance actions, reduction of energy consumption, facilities certification and ensures the verification *of the requisites of the standard ISO 9000'.*

In CBM, asset condition is assessed under operation with the intention of making conclusions as to whether it is in need of maintenance or not and if so, at what time does the maintenance action needs to be executed so that it will not suffer a breakdown or malfunction. CBM is, thus, a type of preventive maintenance that strives to identify incipient faults before they become critical which enables more accurate planning of the preventive maintenance. It is achieved by utilizing complex technical systems or by humans manually monitoring the conditions using their experience.

In CBM, the maintenance action is performed in a predictive manner, where assets condition is the key parameter to determining the maintenance intervals and appropriate maintenance tasks. This means that the system is operated in the most efficient state and that maintenance is only performed when it is cost-effective.

A complete CBM system comprises seven layers (Bengston, 2004) as shown below.

- Layer 1: Sensor Module
- Layer 2: Signal Processing Module
- Layer 3: Condition Monitoring Module
- Layer 4: Diagnostic processing or Health Assessment Module
- Layer 5: Prognostics Module

- Layer 6: Decision Support Module
- Layer 7: Human Interface or Presentation Module

2.2.1 The Sensor Module

This provides the system with digitized sensor or transducer data. The sensor module may be in the form of a specialized data acquisition module with analog feeds from ***legacy sensors***, or it may collect and consolidate sensor signals from a data bus. (Lebold et al, 2004:5)

2.2.2 The Signal Processing Module

This takes data from the sensor module and performs signal transformations and feature extractions such as filtering, spectrum analysis, multi-resolution decomposition etc (Bengston, 2004:3)

2.2.3 The Condition Monitoring Module

On receiving data from layer 2 Module, the condition monitor compares this data with the expected values or operational limits and output enumerated condition indicators such as level low, level normal, level high etc. Besides, it generates alerts based on defined operational limits.

2.2.4 The Health Assessment or Diagnostics Module

The function of the module is to determine if the health of a monitored system, subsystem, or a piece of equipment is degraded. It may generate a diagnostic record that proposes one or more possible fault possibilities with an associated confidence. (Lebold et al, 2004:5)

2.2.5 The Prognostics Module

'Prognostics' means prediction. Thus, this layer tends to predict the future condition of the monitored system, subsystem, or component by making use of the data from any of the previous layers depending on the model approach used. Some of the model approaches are discussed in the technical papers reviewed. The prognostics module can also estimate the 'remaining useful life' (RUL) of an asset.

These two features of the prognostics module have a tremendous influence in asset maintenance.

2.2.6 The Decision Support Module

The primary function of this module is to provide actionable recommendations such as maintenance actions, alternatives on how to run the system, subsystem or component until mission is completed etc. It does this by making use of data from the previous layers.

2.2.7 The Human Interface or Presentation Module

This is also called the layer of access; that is, it gives a user access to information provided by the decision support layer or any other layer with useful information.

2.3 The HART Protocol

Perhaps this is the most important component of integrated control and asset management. HART stands for *highway addressable remote transducer.* It is an early implementation of ***Fieldbus***, a digital industrial automation protocol. The HART protocol is an industry standard developed to define the communications protocol between intelligent field devices and a control system. HART is the most widely used digital communication protocol in the process industries, with over eight million HART field instruments installed in over 100,000 plants worldwide. (How Sensors Work, 2006). HART is at the heart of asset management of field devices (such as transmitters and analyzers) and valves.

The HART protocol makes use of the Bell 202 Frequency Shift Keying (FSK) standard to superimpose digital signals at a low level on the 4–20mA analog signal. This allows two-way communication to take place and makes it possible for additional information beyond just the normal process variable to be communicated to/from a smart field instrument.

The HART signal is shown in the figure 2. The HART protocol communicates without interrupting the 4–20mA signal and allows a host application (master) to get two or more digital updates per second from a field device. Integrated control and asset management has been made possible by the HART technology. This technology does provide asset management capability for field assets

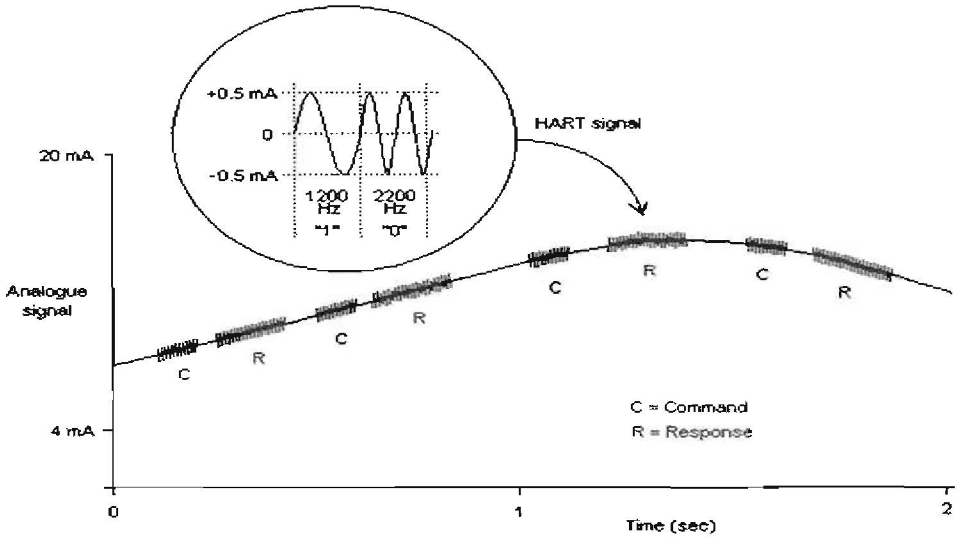

Figure 2: The HART signal

such as instrument transmitters, SMART valves and sensors. Being electromechanical devices, the conditions of such assets are monitored by building intelligence within the devices so that while performing their primary function of measuring and controlling process variables, they are also monitoring their own health condition and reporting its status, thus enhancing the management of such assets .

One way to optimize industrial processes is to reduce process variable uncertainties. (Smart, 2002) This can be achieved by

- Improving accuracy of measured variables
- Reducing sources of measurement errors under actual field condition
- Improving devices stability to ensure desired performance is maintained over extended periods and changing field conditions
- Reducing response time to generate a representative process variable signal.

This is a unique approach to optimizing the control loop.

By analyzing specific characteristics and trends in noise, field devices can identify and signal potential problems with process variability or other physical assets (pumps, valves, etc) in a control loop.

While the 4-20mA analog signal is used for communicating process variables, the superimposed digital signal is used for monitoring the condition of the field devices. The term 'integrated control and asset management' originates from this concept. Thus, there is a composite signal that carries both the process control information and the condition monitoring information. These are then later separated for their intended uses. This superimposition of signals obviates the need to run extra cables to carry the condition monitoring signal.

The physical layout of a single loop configuration of an ICAM system is shown in figure 3

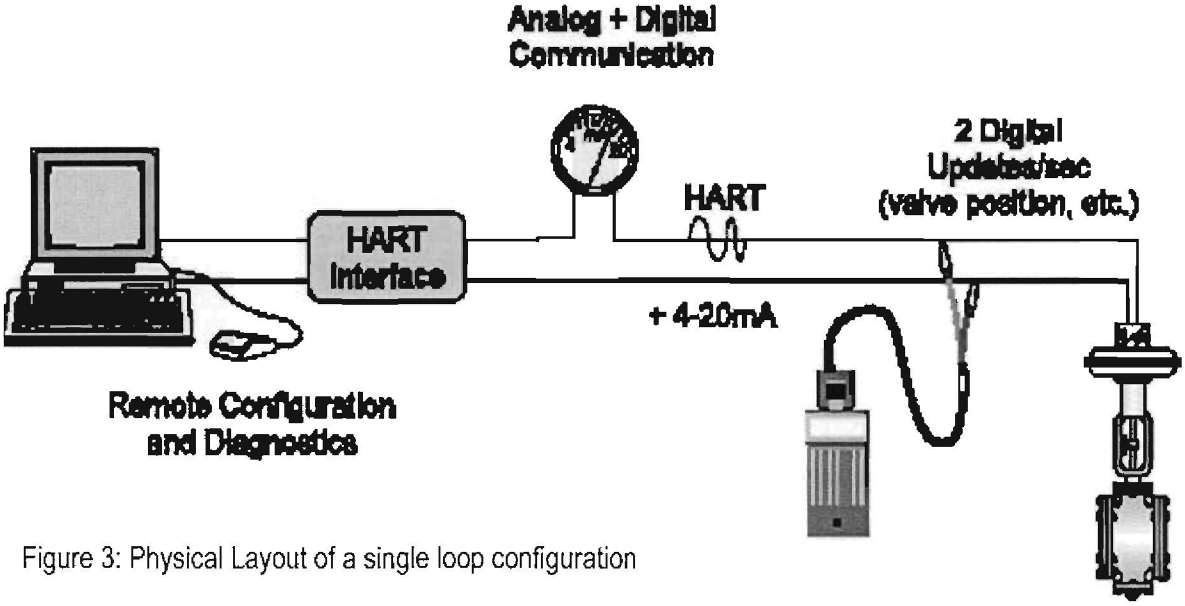

Figure 3: Physical Layout of a single loop configuration

2.4 SMART Field Devices

The development of SMART field devices has also contributed in no small measures to the practical realization of integrated control and asset management. SMART instruments are one of the key components of integrated control and asset management. Increases in processor speeds, data storage and miniaturization have brought about devices that are both smaller and more powerful.

Today, microprocessors are now being incorporated directly into basic plant equipment such as transmitters, valves and process analyzers, thus making them behave intelligently. Unlike in the past, these devices now behave as small data servers with a certain degree of rational decision-making. For instance, a few years ago, a basic transmitter would send one 4-20mA signal back to the control system as an indication of the measured value. Today, the same device with the aid of built-in intelligence sends back multiple readings with six different alarm conditions.

Figure 4 shows typical messages sent to the control system by the intelligent devices.

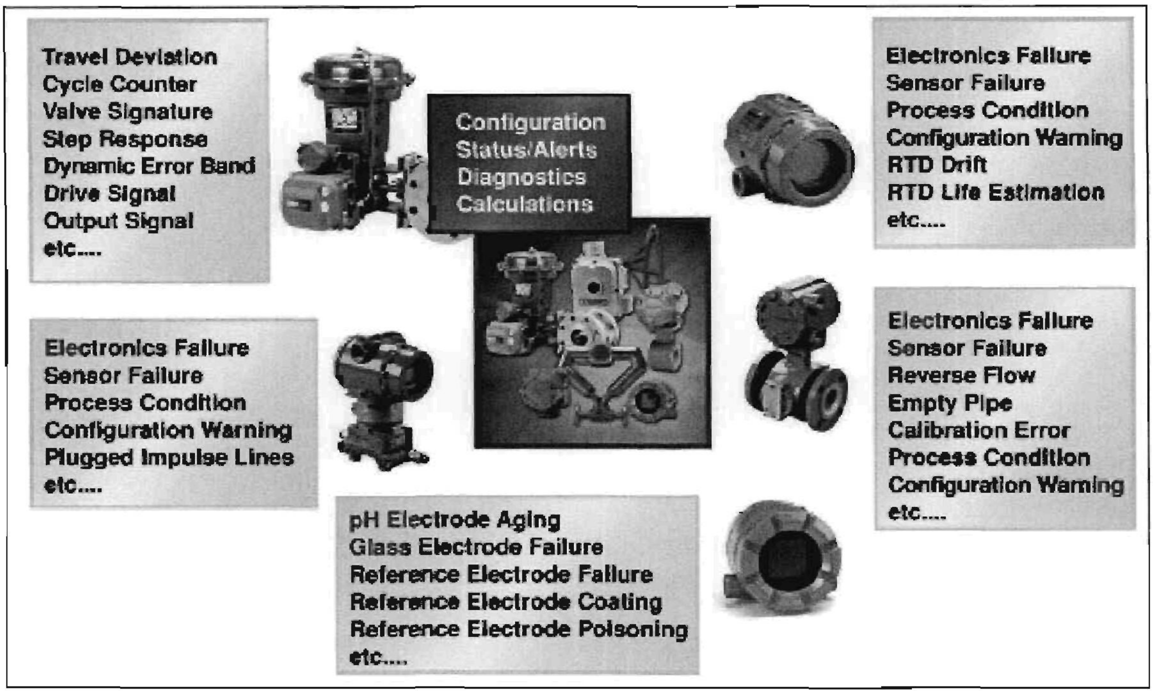

Figure 4: Typical messages from intelligent devices (Anon, 2004)

2.5 ICAM Architecture

Taylor et al (2005:3) developed a conceptual architecture for integrated control and asset management for abnormal situations management which could arise as a result of process upsets or equipment malfunction. The proposed architecture of the system, illustrated in figure 5, consists of four information processing layers and three vertical subsystems, namely, perception, central processing, and action. In the horizontal layers above the DCS, there are semi-autonomous agents that represent different levels of data abstraction and information processing mechanisms of the system.

Through the DCS, the middle two layers (i.e. the reactive and deliberative layers) interact with the external environment and hence the industrial process by acquiring perceptual inputs and generating actions. If a lower layer cannot handle a problem it will pass control to the upper layer to resolve the conflicts in the architecture or notify the operator that it cannot do so. This way, there is less process operation's dependence on the operator. The architecture shows the technical concept of integrated control and asset management. However, in real world implementation, it does not come as a complete system as depicted in the diagram. It is a concept that is applied by combining several components often from different equipment vendors in a manner that realizes the system above.

The block diagram in figure 6 illustrates how this concept is implemented in a real-world situation.

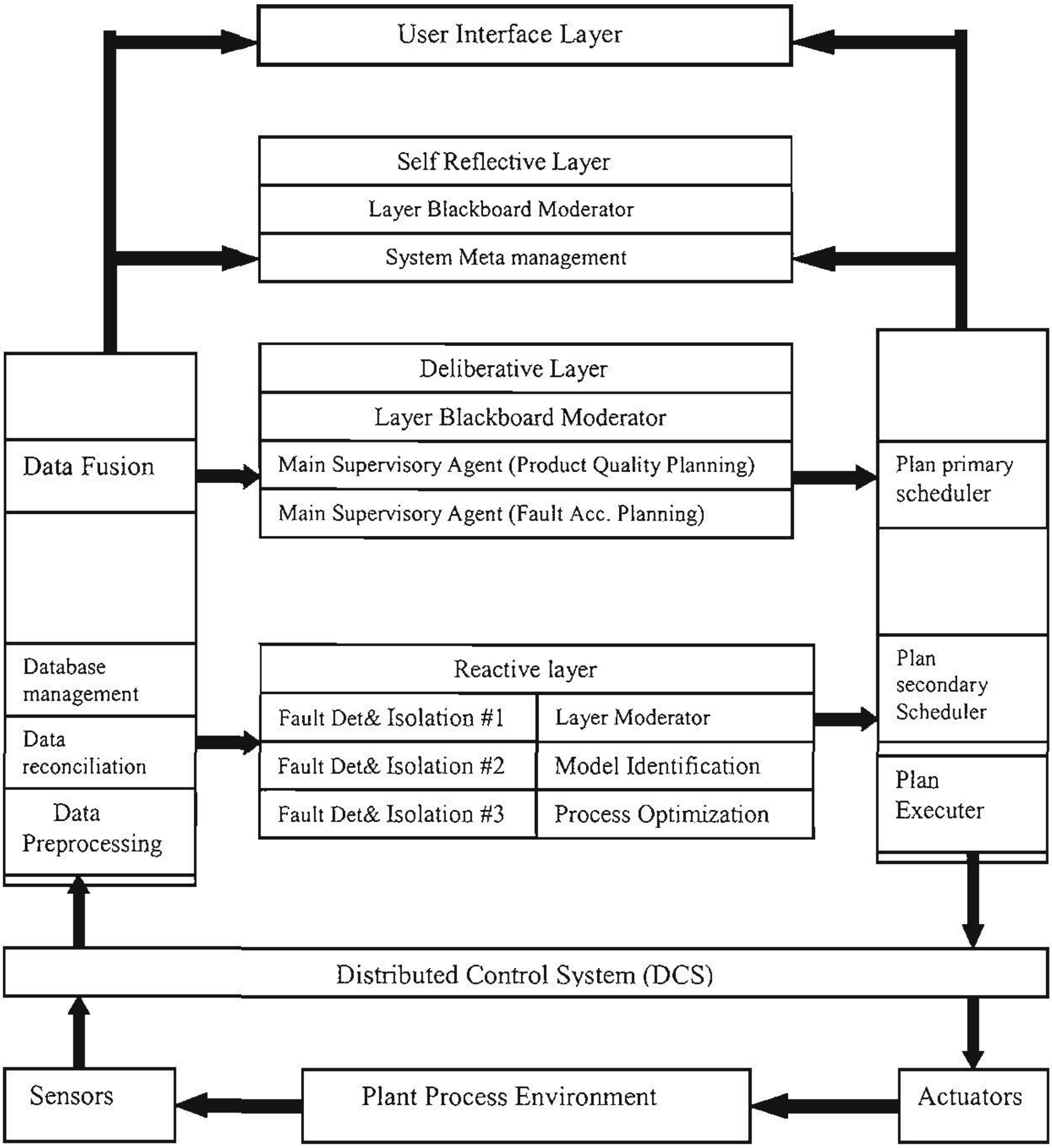

Figure 5: ICAM Architecture

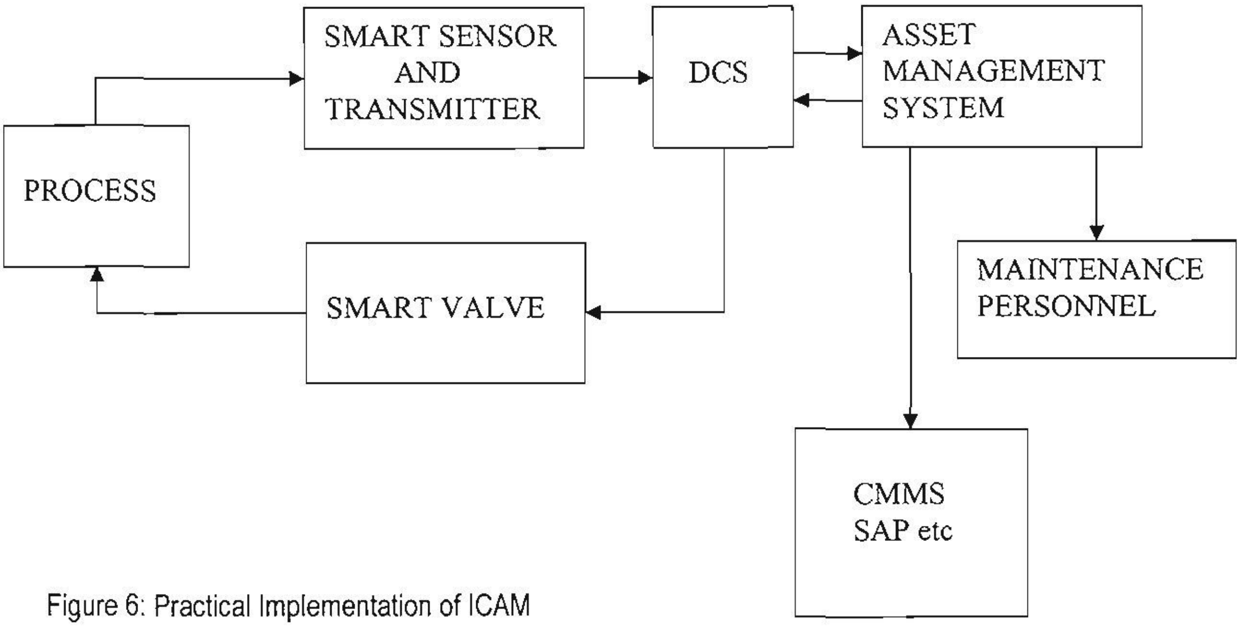

Figure 6: Practical Implementation of ICAM

Virtually all the layers above the DCS in figure 5 are embedded in the asset management system block shown in figure 6. The asset management system block (figure 6) comprises several tools that perform the different functions described in the layers above the DCS (figure 5).

2.6 Technical papers review

Reeves (2006) reports that SMART analytical field devices have now been developed specifically for one type of machinery – the AC induction motor coupled to a centrifugal pump, the most common type of motor-pump machine train found in process industry plants. These units, he said, receive continuous vibration inputs from six different locations on a motor pump train, plus tachometer readings for shaft speed, motor flux inputs from a flux coil, and temperatures measured at the motor surface.

Each vibration input delivers 6400 data points for analysis by the device every 20s. A machinery health transmitter combines and instantly analyses all these information, generating a composite view of current performance characteristics of the machine. Operators and maintenance personnel are then able to see in real-time the dynamic interaction between the process and the operating machine and the effect that the process is having on that machine.

The writer in this article advocates that asset management through condition monitoring can help operators operate a piece of equipment in an optimal manner. The condition of the equipment is not just monitored; operators are able to see how process conditions affect the performance of the equipment. This will better inform the operator on how to run the process with an eye to the assets that make the process to run while still meeting production targets. This paper confirms that to achieve effective asset optimization, condition monitoring is sine qua non. The paper, however, dealt only with an electromechanical machine; nothing is said regarding instruments and valves. Notwithstanding, the idea can be applied to them.

Ciarapica et al (2006) emphasized on the prediction of possible faults and the calculation of remaining useful life of a machine using neuro-fuzzy networks. The paper attempts to improve on the predictive capabilities of the present Condition-Based Maintenance (CBM) system by combining the reasoning capabilities of fuzzy logic with the learning capabilities of the neural network using multi-layer perceptron.

This was applied in analyzing the vibration signals obtained from a high-pressure boiler feed pump in order to determine the condition and status of the machine. This, according to the authors, proved more accurate in adapting input data to output data; which means it has much lower root mean square error (RMSE). The implication of this is a more accurate prediction of incipient faults.

The writer in this paper considered the use of artificial intelligence techniques in spotting incipient faults and predicting the RUL of a machine; but again, it was only with reference to process equipment. Will a similar success be achieved if applied to field devices? Artificial intelligent tools, as discussed by Ciarapica et al (2006) indeed form the backbone of ICAM. These tools are utilized in the complex and sophisticated functions of the asset management system block of figure 6. The exact time or period that a component will fail can be predicted. Also, the asset can be utilized in an optimal manner and unnecessary maintenance costs eliminated since maintenance is only done when required.

Jardine et al (2006) focused on Diagnostics and Prognostics (layers 4 and 5) of the OSA-CBM model. However, in approach, they differed with the authors whose papers were discussed in the foregoing. They underscored the fact that while diagnostics deals with fault detection, isolation and identification prognostics deals with fault prediction. To achieve these in a more improved fashion, therefore, three processes which are sine qua non to diagnostics and prognostics must be improved upon. They are

- data acquisition
- data processing
- maintenance decision-making

In essence, they are not concerned about the predictive model, but the integrity of data the model will use for its predictions. That is to say, even the best predictive model (e.g. a neural network) is only as precise as the data fed into it is precise.

The writers further argued that too much emphasis has been on the condition monitoring data while event data, which include information on what happened and/or what was done to the targeted physical asset, has been neglected. To them, event data and condition monitoring data are equally important to asset optimization. And so, they recommend implementing and automating event data collection and reporting in the maintenance information system.

Though it sounds plausible that incorporating event data with condition monitoring data will better inform the diagnostics and prognostics models, this is yet to be proven. It is my considered view that event data will add little or no value to diagnostics and prognostics. This is not to say event data is altogether useless. In diagnostics and prognostics, condition monitoring data will suffice. I quite agree with the writers that the data need to be precise.

In the work Hulshof et al (2004), an attempt was made to improve on the diagnostics capability of the CBM system through the gathering of advanced (multidimensional) data such as visual images. The paper focuses on how to locate the weak spots in critical installations (headers, steam drums etc). The use of speckle image correlation analysis (SPICA) system was adapted to measure deformation due to creep in critical areas like the heat-affected zones in welds. This involves making an optical fingerprint of the surface of a construction element on the basis of textual features. A recorded image of a rough surface is used as a fingerprint of the object surface. Two

images, one recorded before and one after loading are compared by image correlation in order to determine the strain distribution due to loading.
Through this technique, a fatigued spot can be located. According to the authors, the technique proved better and more precise than the traditional magnetic particle inspection, ultrasonic inspection, visual inspection etc.

Though this technique is good for condition monitoring of pipes, vessels and other process equipment, it is impertinent in valves and instruments. Image pattern recognition is unserviceable in applications that involve field devices.

Marseguerra et al (2002) took a somewhat different approach to asset management. They focused on the decision-support layer of the OSA-CBM model. They were interested in optimizing maintenance decisions by synergizing genetic algorithm (GA) and Monte Carlo (MC) simulation for maintenance decision-making, so that the twin objectives of profit and availability are maximized.
Given that the diagnostics and prognostics have done their jobs excellently, how then do we take maintenance decisions that will maximize profit and availability? This is what the paper investigated. The MC simulation provides a more realistic modeling of a component's degradation process, while the GA searches the proper system degradation threshold beyond which maintenance has to be performed so as to optimize the system mean availability over the mission time and the net profit gained from the operation of the system throughout the mission period.
This technique, according to the authors, proved far superior to existing techniques.

Optimization of maintenance decision-making is a crucial part of asset management. I strongly agree with the authors that the system should not just stop at telling us when maintenance is necessary but go beyond that by informing us the best time to do maintenance.

Chen et al (2005) focused on maintenance policy optimization of condition-based preventive maintenance problems. To achieve this, a semi-Markov decision process (SMDP) model was built to capture the system behaviour, determine at which deterioration stage the system is, at every decision epoch – the system has been divided into various liminal levels – and the best maintenance action, depending on which threshold level it is at the point in time, is recommended.

The recommended maintenance action could be "no action to be taken," "minimal maintenance to be performed," "major maintenance necessary," etc.

This paper is in concert with what was proposed by Marseguerra et al (2002).

In the work of Schneider et al (2006), the authors considered the optimal utilization of the remaining life of an asset regarding a given reliability of service and a constant distribution of costs for reinvestment and maintenance ensuring a suitable return. They took a holistic approach to asset management by considering the life-cycle costs of the equipment and of the system on one hand and the quality of service delivered by the system, as the dependency between costs and quality on the other hand.

This is a macro view of asset optimization unlike most of the approaches gone before which dwelt at the micro level. For asset management to live up to the required expectation, it has to meet four key challenges, the authors argued.

- Alignment of strategies and operations with stakeholder values and objectives
- Balancing of reliability, safety and financial considerations
- Benefiting from performance-based rates
- Living with the output-based penalty regime

The authors raised pertinent thoughts in this paper. And as shall be shown in chapter four (analysis of results and discussions), integrated control and asset management is a tool that helps in achieving this. Through ICAM technology, the lifecycle valuation of an asset can be performed and a balance between reliability, safety and financial considerations achieved.

Smith et al (2002) considered the development of a prototype system to provide real monitoring of an airport ground transportation vehicle with the objective of improving availability and minimizing field failures by estimating the proper time for maintenance. Because of the non-linear behaviour of the system, back-propagation neural networks were chosen as the primary predictive modeling tool. The neural networks were trained using observations data collected from the system under investigation. Once trained, the network was able to recognize patterns similar to those it was trained on and classify new patterns accordingly. Through this, the model was able to provide early detection and isolation of the precursor and/or incipient fault condition of the ground transportation vehicle door system and also able to manage and predict the progression of this fault condition to component failure. The model, according to the authors, proved superior to the existing approaches.

Artificial neural networks (ANN) have been proven to be very useful in pattern recognition and ANN is not an exception in the ICAM technology. In fact, the ICAM system incorporates artificial intelligence tools. Though the application was on the ground transportation vehicle door system of an airport, the approach is equally applicable in field instruments and valves. Through ANN, incipient faults in valves and instruments can be detected as discussed by the authors for the mechanical component.

Bunks et al (2000) focused on performing CBM on machinery components by using the traditional vibration measurements. The primary challenge was to achieve a high degree of precision in classifying a machine's health given that its vibration characteristics will vary with many factors not all corresponding to defective components.

Because it is important to be able to differentiate between vibrational changes which are due to machine component defects and those due to changing operating conditions, a 'Hidden Markov Model' (HMM), well suited to modeling quasi-stationary signals, was chosen to perform detection and estimation for machine diagnostics and prognostics. This was applied to a helicopter gearbox which was operated at various torque levels and with varying seeded defects in a special test rig and the result proved quite robust.

Vibration analysis is not required in condition monitoring of field devices and valves. However, the technique of using a Hidden Markov Model to identify and distinguish vibrational changes due to component defects from those due to changing operating conditions can be utilized in asset management of field devices and valves where patterns that described component defects are closely related to those of other factors not essential to diagnostics. I do not mean using vibration analysis per se but using the concept of HMM to achieve this. This will be particularly useful in minimizing, if not eliminating, false diagnosis due to fallacious fault patterns in the condition monitoring data.

At the June 2003 Iris Rotating Machine Conference in Santa Monica, CA, presenter James R. Rasmussen (2003) identified four evolutionary levels of asset management.

Level 0:

Early asset management techniques, he argued, depended on operators to feel, hear, smell, and see the condition of machinery. This method of sensing obviously led to breakdown maintenance, as early warning of a problem was minimal. As a result of the inability to predict when a component failure was imminent, many operators adopted a time-based maintenance methodology.

The negatives associated with time based maintenance are both financial and operational. If the maintenance interval chosen is much shorter than the mean time to failure of the component being maintained, unnecessary maintenance monies are expended on repairing an asset that does not require repair.

On the other hand, if the maintenance interval chosen is too long, component failure is risked along with the secondary damage that could occur to adjacent components and the financial issues of a forced outage.
For obvious reasons, most time-based maintenance schedules utilize conservative maintenance intervals.

Level 1:

This involves adding installed systems for monitoring plant parameters. These systems continuously monitor the chosen parameter and provide alarm and trip of the machinery in event of a significant change in the measured parameter.

This improved level of monitoring and protection does give the plant operator and maintenance engineer an early warning of impending problems, but with minimal information. However, it is difficult to estimate the time between warning and failure.

The diagram in figure shows level 1 asset management which incorporates Monitoring and Protection System

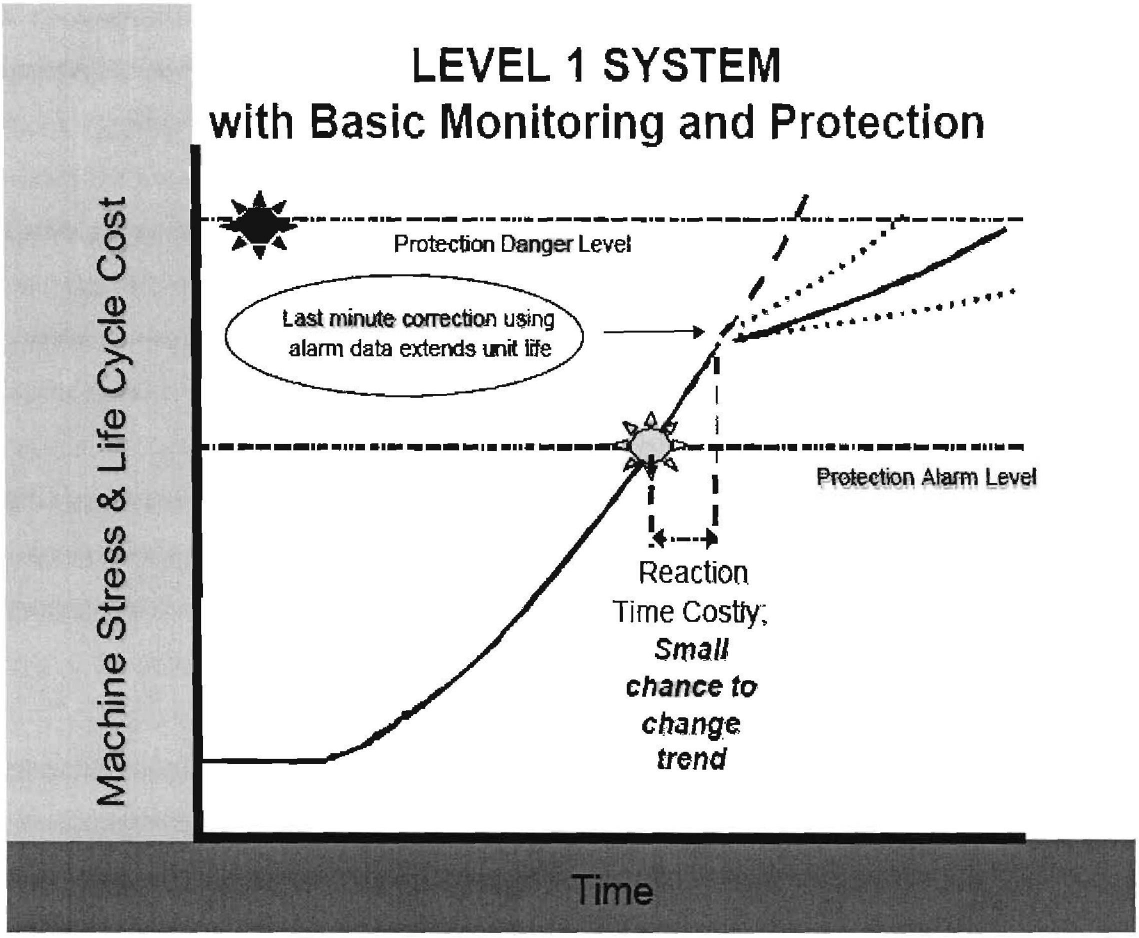

Figure 7: Level 1 with Monitoring and Protection System. (Rasmussen, 2003)

Level 2:

As depicted in Figure 8, this level adds hardware and software to facilitate continuous data acquisition and storage for manual analysis. This enhancement allows for the application of smarter alarms which can provide earlier warning of impending problems signified by the lower horizontal line labeled Asset Management Alert Level.

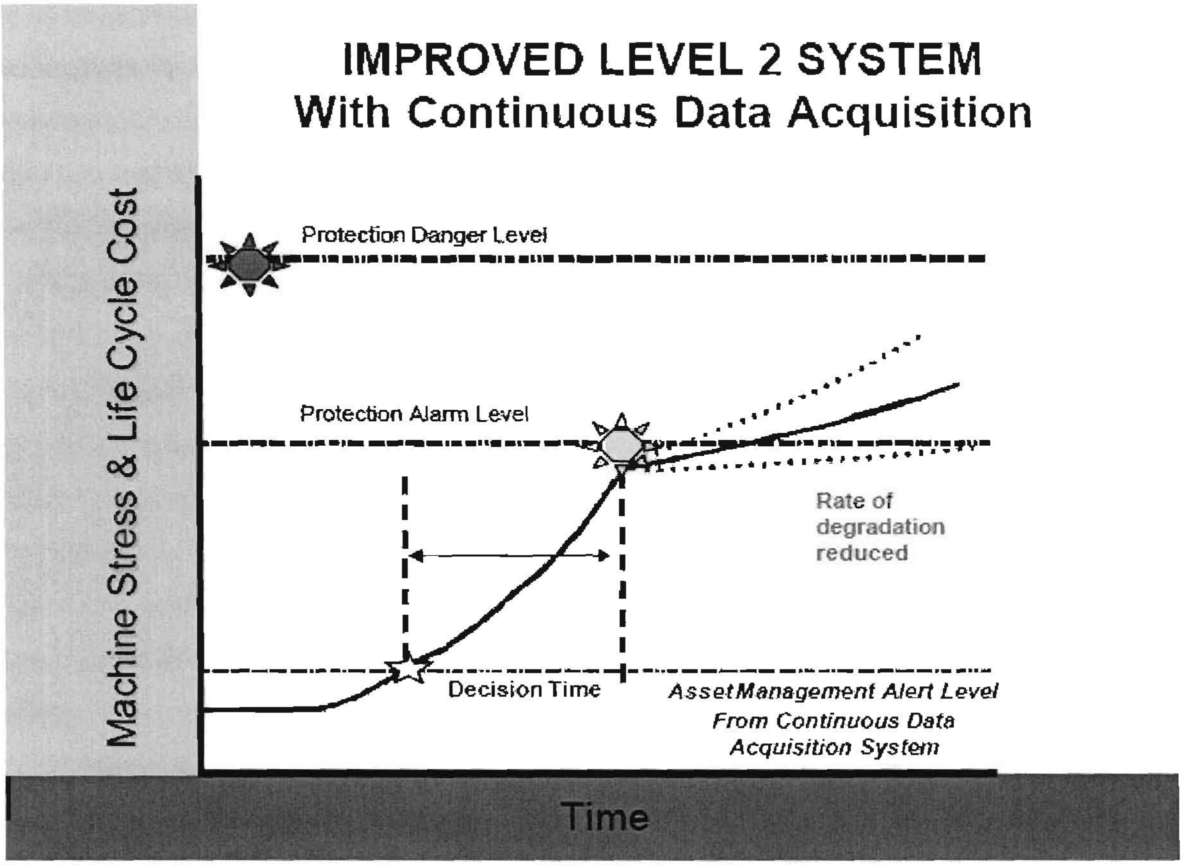

Figure 8: Level 2 with Continuous Data Acquisition. (Rasmussen, 2003)

Level 3:

Level 3 asset management adds knowledge-based computer systems to continually analyze the on line data and provide useful (actionable) information to the plant operator and maintenance staff. The goal of the level 3 asset management system is to manage the operation of the machine below the asset management alert line as depicted in Figure 9. Obviously an electro-mechanical system will eventually wear out and fail; so, the goal of plant asset management is to keep the machine operating below the alert line as long as is economically reasonable.

To meet this goal we must perform the following steps:

- Collect all of the necessary data: This includes not only machine data but also process data and business data so the analysis can consider financial issues in addition to machinery condition.
- Continuously analyze data and convert it into information.
- Characterize the information into alert levels

- Communicate the information to the proper individuals

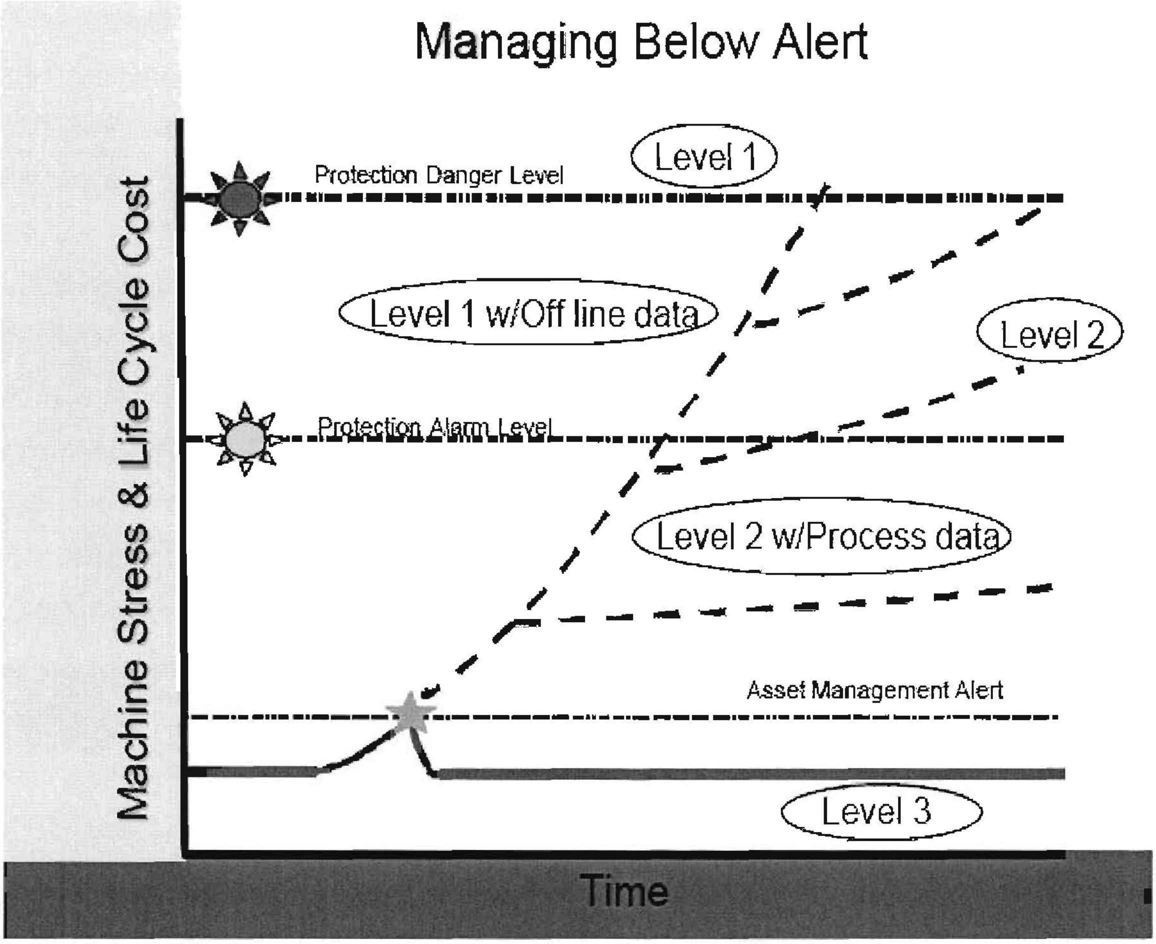

Figure 9: Level 3 Plant Asset management. (Rasmussen, 2003)

When these steps are followed, a condition-based maintenance program can be successfully implemented. When condition-based maintenance is employed, no maintenance is performed when it is not needed. As well breakdown is avoided, eliminating the likely secondary damage and lost production associated with forced outages. Thus, the cost of maintenance falls and equipment life is extended.

CHAPTER 3

3.0 RESEARCH DESIGN AND METHODOLOGY

In chapter two, a review of relevant literatures, underlying technologies, and key concepts in integrated control and asset management was presented.

The HART protocol was specifically given attention because the searchlight of this work is directed at the asset management of field instruments and valves. Also, many claims were made vis-à-vis the benefits of asset management.

This chapter focuses on the research design of the empirical investigation of the problem statement with a view to achieving the projective objectives.

As a reminder, the main objective of this project is: *"to quantify the benefits, monetary and otherwise, of investments in integrated control and asset management in two leading Sasol plants viz Auto-thermal reforming (ATR) plant and N-Butanol plant, and to scientifically verify the claim that integrated control and asset management yields optimized process operation."*

3.1 Research Design

This research work is exploratory in nature. This is obvious from the nature of the research question and objectives. In order to achieve the stated objectives, only an exploratory approach will produce the relevant results that address the problem statement.

Being exploratory, a qualitative rather than quantitative approach to data collection and analysis is pertinent. Hence, not much hard numeric data is generated.

Project hypothesis

In order to accomplish the objectives of this project, a relevant hypothesis needs to be formulated. And the proper hypothesis in this case is that

"Integrated control and asset management gives rise to optimized process operation and decreased downtimes'

3.1.1 Research Tactics

This refers to specific details I used in implementing the research design. It was impractical to conduct a census (i.e. gather required data from every member of the target population) due to very large target population size, geographical location, cost, and time constraints. Only a sample, a subset of the target population, was selected and interviewed. And this sample is sufficiently representative.

A sampling plan was thus prepared which addressed the following issues

- Data requirements
- Target population
- Sampling unit
- Sampling method
- Sampling frame

3.1.1.1 Data Requirements

The following data requirements were identified

i) Type of asset management software in place
ii) Type of control system software in place
iii) The age of the plant
iv) The total number of instruments and valves installed
v) The number of instruments and valves which are SMART capable
vi) Industries patronage of asset management software
vii) The frequency of plant trips
viii) Causes of these trips
ix) Losses incurred in every trip
x) Maintenance strategy in place
xi) Management thinking regarding investment in asset management technology
xii) Readiness to imbibe world class best practices
xiii) Return on investment
xiv) Limitations of asset management system

3.1.1.2 Target Population

This refers to the community of people who possess the information sought by this research study. In this research, the following target populations were identified

i) Control and Instrumentation managers, engineers and technicians who have asset management system installed in Sasol
ii) Control and Instrumentation managers, engineers and technicians who do not have asset management system installed in Sasol
iii) Sasol plant managers
iv) Sasol production managers
v) Sasol plant operators
vi) Asset management system vendors
vii) Maintenance managers, engineers and technicians in Saol

3.1.1.3 Sampling Unit

A sampling unit is the person, company or product which can be physically identified for interview or measurement on the specific variables identified. So, several persons were penciled down for interview from within the target population. These people included

i) Sasol Infragas asset management representative
ii) ATR plant manager
iii) ATR plant control and instrument manager
iv) ATR plant production manager
v) ATR plant control and instrument engineers and technicians
vi) N-Butanol plant engineering manager
vii) N-Butanol plant reliability manager
viii) N-Butanol plant control system engineers
ix) N-butanol plant electrical and instrument supervisor
x) Sasol technology control and instrument engineers
xi) Alpret Controls (South Africa) engineering representative
xii) Emersonprocess management control and instrument representative

3.1.1.4 Sampling Method

In this research, the following factors informed the choice of people within the target population identified for interview.

- Personal judgement
- Accessibility

Personal judgement and accessibilty were used to draw this sample due to the following reasons

i) It was necessary to choose persons with particular knowledge of the research area.
ii) Rigorous opinion surveys are not essential
iii) Expert opinion on this technical problem is required and is available only from selected knowledgeable respondents
iv) This research requires in-depth reasoned explanations, rather than masses of numeric responses
v) Respondents should be accessible and generally cooperative

It is pertinent to mention that this methodology introduces potential bias into the data analysis as it is based on the judgment of the researcher, though informed and objective.

3.1.1.5 Sampling Frame

For primary data collection, the sampling frame used included

1. Database of Sasol employees where the contacts (telephone, e-mail and plant location) of type of people which had been identified for interview were obtained.

2. Internet: through search engines like Google and Mamma, relevant companies employing asset management technologies were discovered. The contacts of relevant personnel e-mailed in these companies were obtained as well. Also, contacts of relevant personnel in asset management system vendor companies such as Emersonprocess management, Honeywell, and Alpret control systems Inc, were also obtained.

3.2 Data Collection Methods

Data obtained in the pursuit of this research came from two sources.

- Primary data sources and
- Secondary data sources

Primary data are data that I collected myself through the collection method described below while secondary data already existed in processed form.

Data also came from internal and external sources. For internal data collection, two plants were empirically investigated in Sasol, the N-Butanol plant and the Auto-Thermal Reforming plant (ATR). These plants were chosen because they are relatively new plants. As a result, the installed field devices and valves have capabilities for asset management functionalities using predictive technologies. The older plants were left out because they have no capacity for an asset management system.

An attempt to implement the system in these plants would be financially prohibitive. It would mean that all valves and transmitters would have to be replaced as most of them are not SMART devices.

3.2.1 Primary Data Collection Methods

Two approaches were used to gather primary data.

1. Observation Approach
2. Survey Approach

3.2.1.1 Observation Approach

Direct and protracted observation was made in the way the Auto-Thermal Reforming (ATR) plant conducted its operations for the period between June 2006 and August 2007. Within the period, a number of plant trips were witnessed. Also, three major shutdowns (for maintenance) were experienced.

Particular attention was given to

- The frequency of plant trips
- The losses incurred when the plant trips

- The approach to maintenance
- The installed base of SMART field devices
- The efficiency of the plant's operation process
- The number of alarms a panel operator attends to everyday
- The usage level of the asset management system in place
- The skills level of the instrument technicians

Besides this, personal study was conducted on the asset management system and many revelations were discovered.

3.2.1.2 Survey Approach

Surveys were conducted using the following approaches

- Personal interview
- E-mailed surveys
- Telephone interviews

At least twenty (20) experts on asset optimization, control systems and plant maintenance strategies were interviewed either through personal interview, e-mail or telephone interviews. These experts include control and instruments engineers, plant managers and maintenance managers within Sasol.

The number is relatively small because experts in integrated control and asset management system are very few. Also, this technology is relatively new in South Africa.

The advantages derived from the primary data collection methods used include

- Direct relevance to the problem being researched
- Greater accuracy and reliability of data due to greater control over the collection process

However, it was time-consuming and generally more expensive to collect the data as several appointments had to be made to be able to get each respondent. Also, e-mailed respondents hardly respond to their mails on time.

3.2.2 Secondary Data Collection Methods

As said earlier, secondary data used in this research already existed in processed form. This data came, principally, from operations and maintenance history of the ATR and N-Butanol plants of Sasol. Access time to the data was short and the cost of acquiring it low.

These data, some of which came into existence prior to the occurrence of the current study, were guided by similar objectives with those of the present study, thus making them both relevant and useful for analysis in this research.

The major drawback of the secondary data used is that it does not lend itself to further manipulation.

Besides, not all the desired secondary data could be obtained because some of them were denied due to intellectual property reasons. This particular point is the major limitation suffered by this research pursuit and goes a long way in affecting the results and analysis.

CHAPTER 4

4.0 RESULTS, FINDINGS, ANALYSIS AND DISCUSSIONS

In this chapter, the results or findings of the empirical investigation of the research question are presented. The findings are of two categories.

1. Findings due to the primary source of investigation, i.e. survey and
2. Findings due to the secondary source i.e. plants operational and maintenance history

4.1 Results and Discussions

The findings obtained from the series of interview conducted are qualitative and not quantitative. Hard numeric data that could be tabulated or displayed in a graph could not be generated. Hence, I will be analyzing and discussing them at the same time.

With a view to discovering what the culture was in Sasol vis-à-vis asset management, an interview was conducted with Mr E. Piater (2006), and this interview revealed that in Sasol

i) Maintenance was predominantly reactive; when equipment breaks down, then they fix it.

ii) There was no structured and standardized approach towards maintenance and asset management. Everything was done on a priority planning because there was no solid work management process; and this took heavy toll on budget.

iii) No real benefit vis-à-vis asset management was derived from Sasol's Software Application protocol (SAP) system. The Plant Maintenance (PM) module of the SAP was being grossly underutilized.

iv) There was this large inventory overstock of parts and material of which many may be obsolete

v) Ineffectiveness and inefficiency in Work Management Process

To close this gap, Sasol launched a project called STAR (Sasolburg Total Asset Reliability) in May 2006, with a view to taking the company from where it was to where it ought to be in terms of world class best practices; that is, from reactive to pro-active maintenance. And the vehicle to achieving this is the SAMI asset health care model (see Figure 1). With the launch of STAR, the foundation for implementing stage I (Planning and Scheduling of work) of the model was laid.

A second interview was conducted with the Mr A. Wolmarans (2007). The essence of this was to gauge the management thinking regarding the optimization of the production process.

The interview revealed that the management seeks to achieve 100% operational reliability. And one key factor towards achieving this is having an appropriate reliability strategy. A holistic look is being given to all assets in order to get the maximum return on investment. The entire plant is looked at as a conglomerate of several systems. Each system is broken down and all critical equipment identified, then the relevant maintenance strategy adopted.

On the instruments and valves, the predictive maintenance strategy made possible by the asset management system installed with the control system is being implemented. However, the manager acknowledged that the asset management system installed is being underutilized.

Several verbal communication sessions were held with Mr W. Lategan et al (2007) with a view to discovering the motivation for implementing ICAM technology. These are the control system engineers involved in the implementation of the integrated control and asset management in Sasol plants.

The interview revealed that

i) World class best practices require that plants in modern times should be safer. Therefore, it became imperative to install systems that would help ascertain the safety integrity level of trip systems. That is, to be able to test trip valves for effective operation even when the plant is online.

ii) It was necessary to put in place a system that would enable proactive maintenance of the field devices and valves.

iii) The amount of time and effort spent on control loop checks and calibration of instruments, particularly during the commissioning phase of a plant, is quite enormous. In the past, personnel would have to go to the field with a hand-held device to do loop checks on every control loop in the system and for the calibration of the different devices. With integrated control and asset management, loop checks and calibration are much quicker. Besides, they can be done directly from the control room without any field presence.

iv) Before, it was impossible to visualize how the instruments, valves and the controller are performing. With asset management integration with control system, this was seen as a possibility. Thus, by visualizing how the devices perform, it would be possible to know the reasons why devices fail.

v) An operational opportunity that could lead to monetary savings was identified in reducing or possibly eliminating unnecessary maintenance expenses. In the past, during shutdowns, certain critical instruments and valves have to be taken out for overhauling even when nothing is wrong. This had to be done because there was no system in place that could tell which instrument or valve is actually in need of maintenance. Thus, unnecessary maintenance cost was being incurred. Now, with integrated control and asset management, it can be known beforehand which instrument is in need of maintenance and only such would be removed during shutdown.

In the N-Butanol plant case study, an interview was conducted with Mr J. Claassen et al (2007). The objective of the interview was to determine the motivation for the decision to implement integrated control and asset management in N-Butanol plant and to articulate the benefits, if any, derived so far.

According to Mr J. Claassen (2007), the reasons for implementing ICAM are

i) Due to many years of plant experience, it was discovered over time in the past that whenever plants were designed, maintenance was not factored into the design; therefore, maintenance was predominantly reactive. Also, maintenance was unavoidably costly because it was an afterthought. So, there was the need to solve problems experienced in previous older plants in new designs. In other words, it was essential and logical to implement lessons learned from the older plants in new designs, and N-butanol plant was under design/construction then.

ii) There was the need to make use of modern technology to improve the reliability of the N-Butanol plant. Though only little success had been recorded then with implementation of ICAM worldwide, it was necessary to take that bold step of deploying this technology, though adventuresome at the time.

iii) It was envisioned that by deploying ICAM technology, the design cost due to instrumentations could be reduced besides other benefits derivable. This will be explained later.

iv) The decision was also motivated by the need to try better ways of doing things. ICAM offered this promise though with little evidence at the time.

Other reasons given by these experts for implementing ICAM are not different from what is already highlighted above in the interview with the Sasol R&D Engineers.

4.2 Benefits

The benefits of integrated control and asset management, as found from these interviews and the two-plant case studies are two-fold.

i) Monetary savings
ii) Non-monetary benefits

4.2.1 Monetary savings

The monetary savings derived from ICAM implementation include the following

- ***Cost savings due to removal or reduction of unnecessary maintenance expenses***: In the ATR plant case, the average cost of overhauling a control valve is R5000 while that of a block valve is about the same. This does not include the cost of replacement of any faulty or damage part of the valve assembly. This cost is only meant for normal servicing of the valve. Table 1 shows the numbers and types of instruments and valves installed in the plant. Out of 141 control valves (Pressure, level, temperature, analyzer and flow control valves), only two are non-SMART capable, which means is a sort of SMART plant. Without an asset management system, it would be impossible to know which valve is need of maintenance. It would then mean that each valve would have to be removed for inspection and if necessary overhauled.

Table 1 Instruments and Valves List (ATR Plant)

Type of device	**Total number**	**SMART enabled number**	**Non-SMART enabled number**
Pressure control valves	71	All	-
Flow control valves	39	All	-
Level control valves	16	All	-
Temperature control valves	13	All	-
Analyser control valves	2	-	All
Auto Isolation valves	14	All	-
Block (UXV) valves	285	65	220
Pressure Transmitter	119	All	-
Flow transmitter	92	All	-
Level transmitter	26	24	2
Temperature transmitter	500	All	-
Analyser transmitter	63	All	-

This, obviously, will take a heavy toll on budget. Going by an average overhaul rate of R5000, about R695 000 (i.e. 139 X R5000) would be expended on valve maintenance at least once every two years because the policy is that these must be overhauled every two years even if nothing is suspected. With Integrated control and asset management, this cost has been greatly reduced. The asset management system monitors each control valve, records its health status and decides if it will require maintenance or not. In the September, 2007 shutdown of B train[1] of the plant, for example, only 49 valves were removed for overhauling and the reasons why they were removed

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[1] *The ATR has two identical production trains A and B*

were known even before physical inspection. Subsequent maintenance underpinned the veracity of the ICAM early fault detections, though no noticeable abnormal situation had been recorded in the process operation.

Compared with amount that would have been spent without the asset management system, there have been significant savings. Apart from this, it does not mean also that no valves would break down before the two-year overhaul time. So, the calculation considers the worst case scenario. Besides the savings realized on actual valve maintenance, savings are also realized from reduction in overtime costs as well as reduction in the number of personnel required for maintenance.

In the N-Butanol plant case study, the plant had 10000 instruments and 600 control valves installed. Without ICAM, every control valve is required to be removed for preventive maintenance every two years even if there is nothing wrong, and the average cost of maintaining a control valve is R5000. With ICAM technology in place, only twenty valves have been removed so far in past four years. This has been made possible by the intelligence offered by ICAM whereby it can be known exactly if a valve is in need of maintenance or not.

So, going by these figure, in every two years of the four years stated above
» 600 X R5000 = R3000 000 would have been spent. This gives a total of R6000 000 that would have been spent on valves maintenance in four years. It should be noted that this figure does not include the production time required in isolating these valves as well as the cost of crane services required to pull out the valves.

With only 20 valves removed so far for maintenance in the past four years, the amount spent then was
» 20 X R5000 = R 100 000.
This means a saving of
R6000 000 – R100 000 = R5900 000 in four years.

On the instruments side (numbering about 10 000), significant savings have been recorded as well, as virtually all the instruments are intelligent and they can tell if something is wrong and what is wrong.

Besides the savings recorded on valves and instruments maintenance, there were savings as well in the project cost of instrumentations when the plant was being designed. This was due to the implementation of 'one out of one' trip system made feasible by ICAM technology.

'One out of one' trip system means that only one instrument set such as a pressure transmitter is installed to measure a particular critical process variable and will trip the plant whenever the process variable value goes above or below a certain threshold. The problem with 'one out of one' without ICAM is that the safety is very low. If the instrument goes bad, for example, the reading will be very low or even 0. If such an instrument is configured to trip the plant whenever the process variable value goes above a certain threshold, it would never detect this high value and so the safety of the plant might be in danger. So, one out of one is not reliable if it cannot be known when an instrument is malfunctioning. The other two systems are

- One out of two: In this system, two trip instruments are installed but at least one whose value goes above or below the threshold will trip the plant. This system improves safety significantly but reduces reliability[2] to 50%. This is because you now have two instruments, running in parallel, which could trip the plant independently.
- Two out of three: In two out of three, three trip instruments are installed and at least any two whose values go above or below the threshold will trip the plant. This system is the best of them all but with an added cost. It gives close to 100% safety and also about 100% reliability. However, there is an extra cost of an additional instrument on every trip instrument set.

In Sasol, the normal practice is to implement the 'two out of three' voting system whenever new plants are installed; and with the greater confidence in ICAM technology, an asset management system is also installed.

According to Mr J. Claassen (2007), the argument now is, with ICAM technology, it will be overprotection to install three instruments out of which at least two should trip the plant. It does not mean that the 'two out of three' system should be not be implemented, rather it should be done

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[2] *this does not mean the reliability of the entire plant. It means the reliability contributed by the instruments*

[2] *this does not mean the reliability of the entire plant. It means the reliability*

cleverly and judiciously. It should not be done indiscriminately as is the case with the current control engineers who implement these systems. Since with ICAM in place we can monitor the condition of instruments, 'one out of one' can be mixed with 'two out of three' with the latter installed only when necessary.

This was done in N-butanol plant and it brought about tremendous savings in cost, without impacting on safety or reliability. In fact, the plant's reliability has increased from 97% to 99.5%, according to Claassen. This reliability improvement is due to the contribution of ICAM, all other things being equal. That is, if all the contributions to plant reliability by other assets are very good, that due to ICAM brought about 2.5% increase. The details of this measurement remain within the purview of Sasol's Intellectual Property policy.

- ***Trip prevention***: In the interview with Mr J. Keyser et al (2006), it was discovered that
  - i) About R1.3 million is lost in 24 hours when a train of the ATR plant is down. Should the two trains go down for the same period, the loss will amount to about R2.6 million.
  - ii) The ATR plant has had several trips, many of which are preventable, since inception in 2004.
  - iii) The plant has witnessed more planned shutdown maintenance than estimated at inception. The plant was designed to be shutdown once every two years but now each train is shutdown once a year, giving two shutdowns per year.
  - iv) The loss incurred when a train is down goes beyond the ATR plant alone. All the plants that use the ATR product as feedstock are also affected because they have to cut back on their production.
  - v) The unavailability of a train poses a high risk to Sasol operations because the loss of the second train means grounding of operations in several plants in Sasol One site.

The import of this is that when a train trips or there is an unplanned shutdown a huge amount of money is lost. Instrument failure, particularly trip[3] instruments, is one of the major causes of train trips. Through Integrated control and asset management, it is possible to know when an instrument is most likely to fail. Thus, appropriate actions can be taken before time to save the

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[3] *a trip instrument is one that will initiate a plant trip whenever there is a potentially dangerous or unsafe situation.*

trip. Though difficult to quantify, huge monetary savings can be realized from this. By saving plant trips, uptime increases which increase throughput as well.

The story is the same for the N-Butanol plant. Between R3000 000 and R5000 000 is lost when the plant trips. And with ICAM in place, several incidents that could have led to plant trips have been detected early on time and mitigated.

According to Mr J. Claassen (2007), since the implementation of ICAM, the plant's availability has increased by 5%. This means that out of 365 days in a year, 18 days have been added to the plants uptime. For a plant that makes about R3000 000 a day, this means an increase of R54000 000 in annual profit.

i.e. 18 X R3000 000 = R54000 000

Though the details of how the 5% availability increase was arrived at were not given the measurement was taken over a few years and it was observed that there was increased uptime since the time ICAM was installed. Besides, problems that could have resulted in plant trip were spotted early enough by ICAM and mitigated.

- ***Early planning for replacement***: Integrated control and asset management also brings monetary savings due to early planning for replacement parts. By knowing when an instrument is most likely to fail, parts can be ordered as at when necessary. This will reduce the tie-down of useful capital in unnecessary inventory.

4.2.2 Non-monetary benefits

From the series of interviews conducted and the empirical investigation into the ATR and N-Butanol plants experience, the following non-monetary benefits have been realized.

- ***On-line proof testing***: With integrated control and asset management, tests can be conducted on block valves without necessarily shutting down the plant or interrupting the process. These were impossible in the past. The main test normally carried out online is the *partial stroking* of valves. This is partial movement of the valve stem to ascertain if it will respond when activated. This is normally done on trip valves to ensure that the valve will respond as desired whenever there is a need to shutdown the plant, particularly when situations are unsafe. Before, this could not be done unless the plant is decommissioned.

- ***Calibration, loop checks and controller performance***: Unlike in the past when a technician has to go to the field with a hand-held device to calibrate a device or perform loop checks, all these are now possible right from the control room. This is as a result of an asset management system incorporated with the control system.

- ***Possibility of a proactive priority-based maintenance strategy***: Integrated control and asset management has enabled a more proactive priority maintenance strategy implementation in Sasol. Table 2 below shows the priority guideline used in Sasol.

Table 2 Priority guideline

Symbol	**Description**	**Criteria**
P1	**EMERGENCY** ❖ The work is classified as "reactive" and interrupts the Daily Schedule ❖ The work starts immediately and will normally continue until completed (Around the clock) ❖ Work justifies overtime to completion	❖ Production loss already occurred or imminent threat to loss exists. ❖ Immediate Health, Safety or Environment risk exists
P2	**URGENT** ❖ The work may interrupt the Weekly Schedule ❖ The work shall go through the planning process and will be	❖ If work not started within 7 days, a loss of production could occur ❖ Health, Safety, or Environment issues if not attended to within 7 days will lead to unacceptable

	scheduled to start within 7 days of notification creation. ❖ The work will not start the same day as notification creation.	risks.
P3	**PLANNED** ❖ This work goes through the Work Management Planning Process, is neither an Emergency nor Urgent. ❖ The work does not interrupt the Daily or Weekly Schedules ❖ Normal preventive and predictive work is assigned to this priority	❖ Planned Production will not be effected for 7 days. ❖ Safety, Health or Environment risks can be safely managed for at least 7 days.

With the condition monitoring and predictive capabilities of ICAM, an emerging fault can be spotted on a component and the problem ranked according to the priority it wields. If it is an incipient fault that is likely to trip the plant or cause a major process upset, it is ranked P1 and the appropriate action taken immediately. So, the P1 maintenance does not necessarily have to be until a trip or a major process upset has occurred that the appropriate action is taken. That would be reactive P1.

ICAM offers a proactive priority strategy. The diagram in figure 10 shows the old maintenance workflow while that in figure 11 shows the new maintenance workflow made possible my asset management.

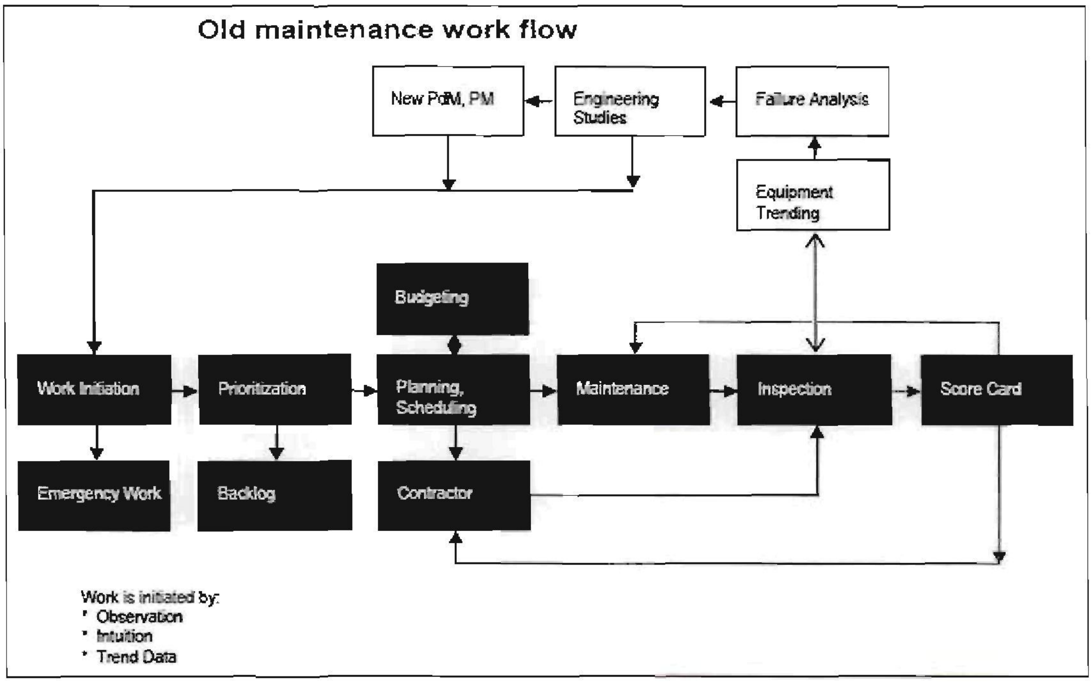


Figure 10: Old Maintenance Workflow.

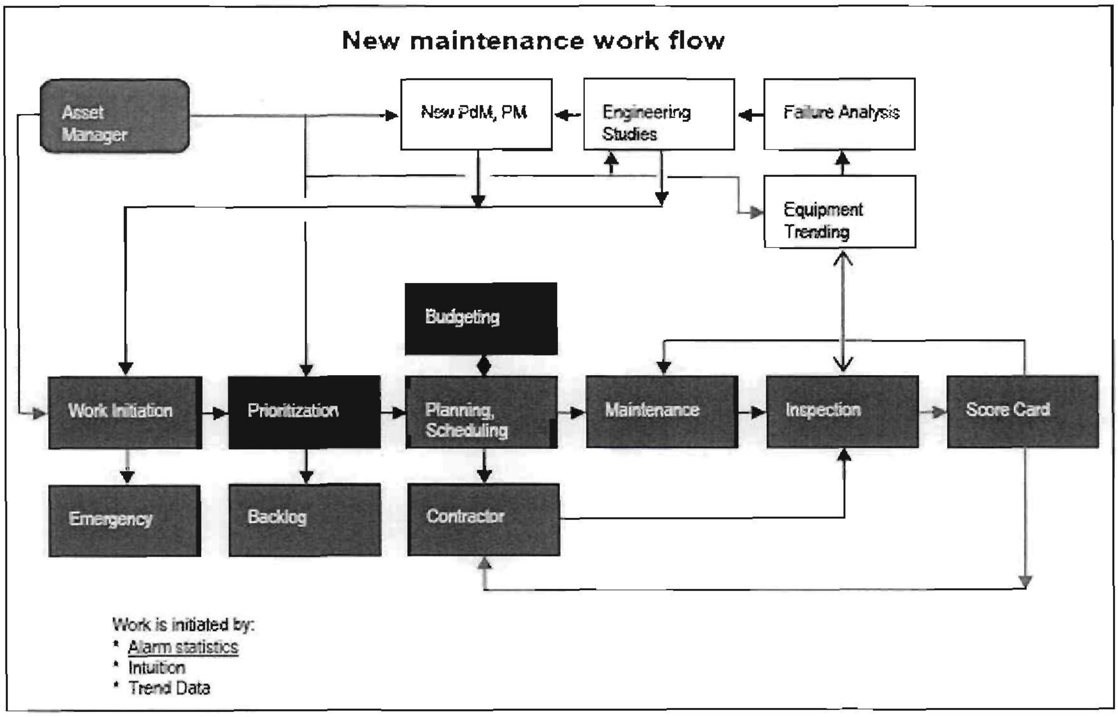


Figure 11: New Maintenance Workflow.

- ***Alarm management***: ICAM also offers the possibility of good alarm management. In the N-Butanol plant case study, it was discovered that each of the 10 000 instruments publishes an average of 100 variables every minute and if there is a deviation an alarm is generated. If all the instruments have one deviation or the other, though very unlikely, there would be about one million alarms in one minute. That is the worst case scenario. Though this is highly unlikely, an operator is inundated with hundreds or thousands of alarms in one day. And the operator must respond to all of these.

  Obviously, this is practically unwieldy. With ICAM, the alarm has been configured such that the operator is presented with only the alarms that are necessary.

- ***Diagnostics reporting***: With integrated control and asset management, the control system engineer or maintenance engineer gets diagnostics reports on each instrument and valve on the field.

  The engineer can know when something is going wrong even at a remote location. This is because the asset management system can be configured in such a way as to notify him of deviations through emails or on his cellphone, thus removing his dependence on the operator for notification.

- ***Build-up of historical data of instruments for lifecycle analysis***: Through asset management, historical data on an asset can be accumulated for some years after which the lifecycle analysis such as failure rate, failure modes, etc of that asset can be performed. To perform lifecycle analysis, historical data is sine qua non.

  To be able to predict the remaining useful life of an asset, for example, data on the performance of that asset over a period of time needs to be gathered. This makes asset management a veritable tool in this application.

  Besides, the artificial intelligence capabilities of the asset management system will not only predict the RUL of the asset but will do so within the context of process conditions in which the asset is being utilized.

- ***Valve signature determination***: Control valves are an important asset in any production plant. They are the final control elements in most control loops; they constitute a significant investment in plant installations.

The ATR plant has about 139 control valves while the N-Butanol plant has about 600 control valves.

Without a proper asset management of valves, considerable amount of money could be lost due to sub-optimal process control. Therefore, valve signatures are used to monitor valve performances.

A valve signature is the characteristic, unique behavioural pattern of a valve under certain conditions. No two valves with equal designs have exactly the same signatures. In the past, it was difficult to determine a valve's signature under actual field conditions. The engineer relies on the one supplied by the manufacturer, which is normally done under simulated and not actual field conditions.

The experience, according to Mr J. Claassen (2007), is that the valve signature under plant conditions is quite different from the one supplied by the manufacturer. With asset management, they are now able to determine a valve signature and use the same for

i) determining if a valve is abnormal
ii) calibrating the valve

Figure 12 shows a typical valve signature for the actuator pressure against the valve stem travel while figure 13 shows the graph of the stem travel against time for a particular valve (PV 40042) at the N-Butanol plant.

The blue line indicates ideal valve signature while the red line shows the actual valve signature.

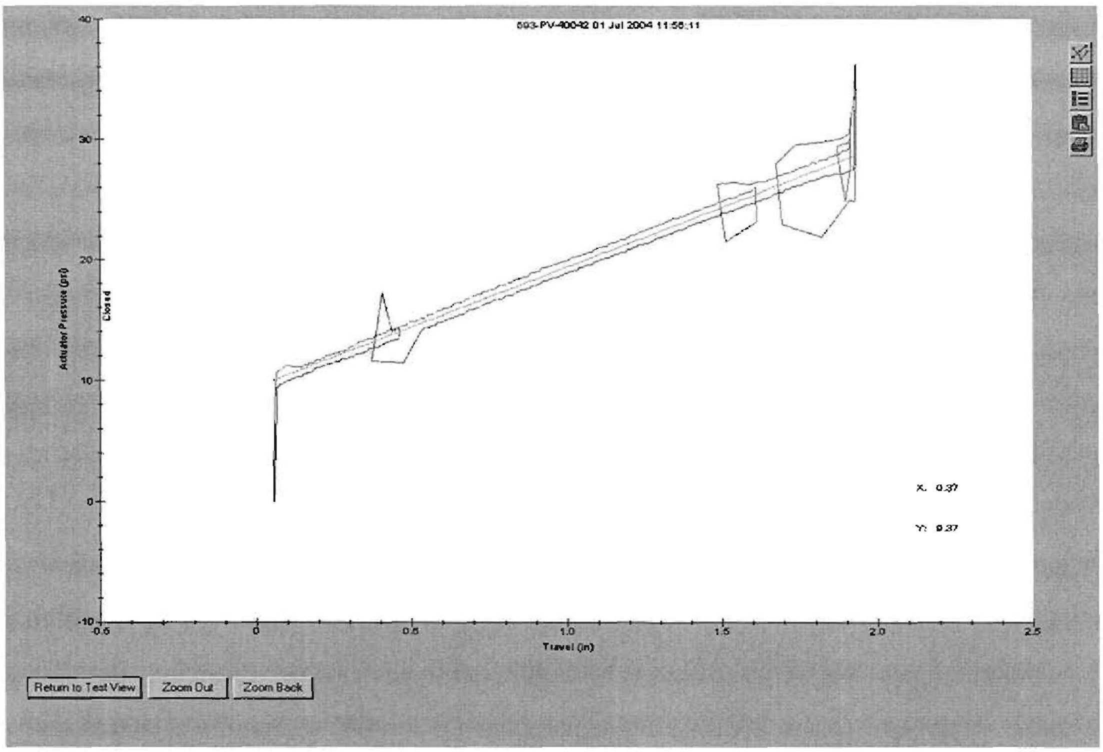


Figure 12: Typical Valve Signature (Actuator Pressure against Stem travel)

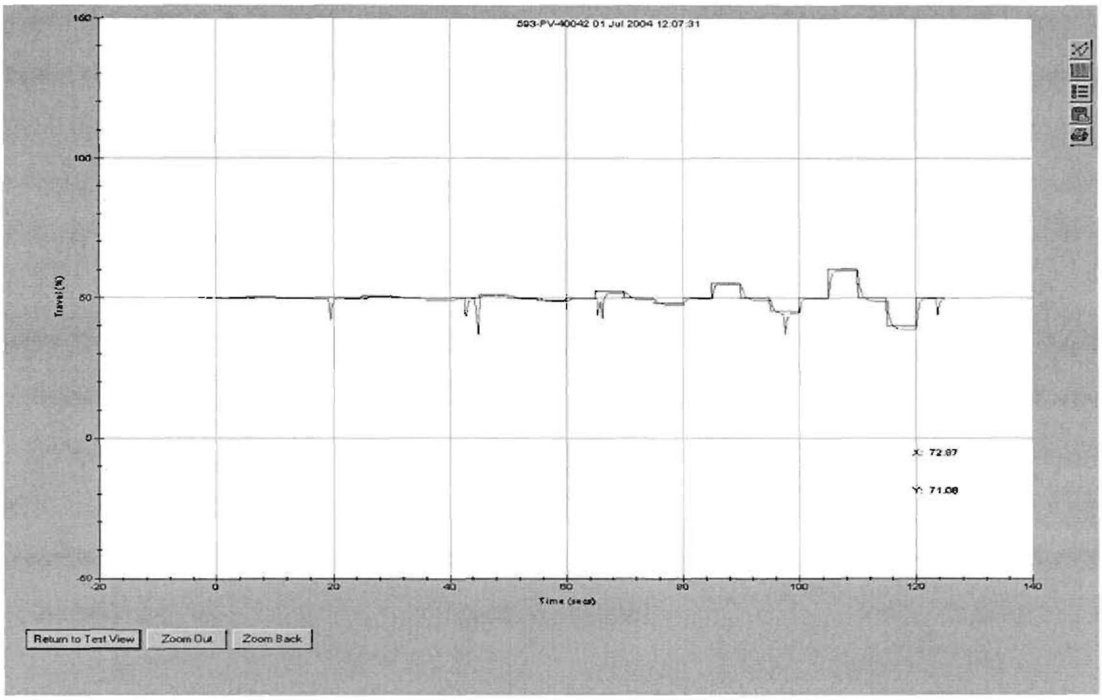
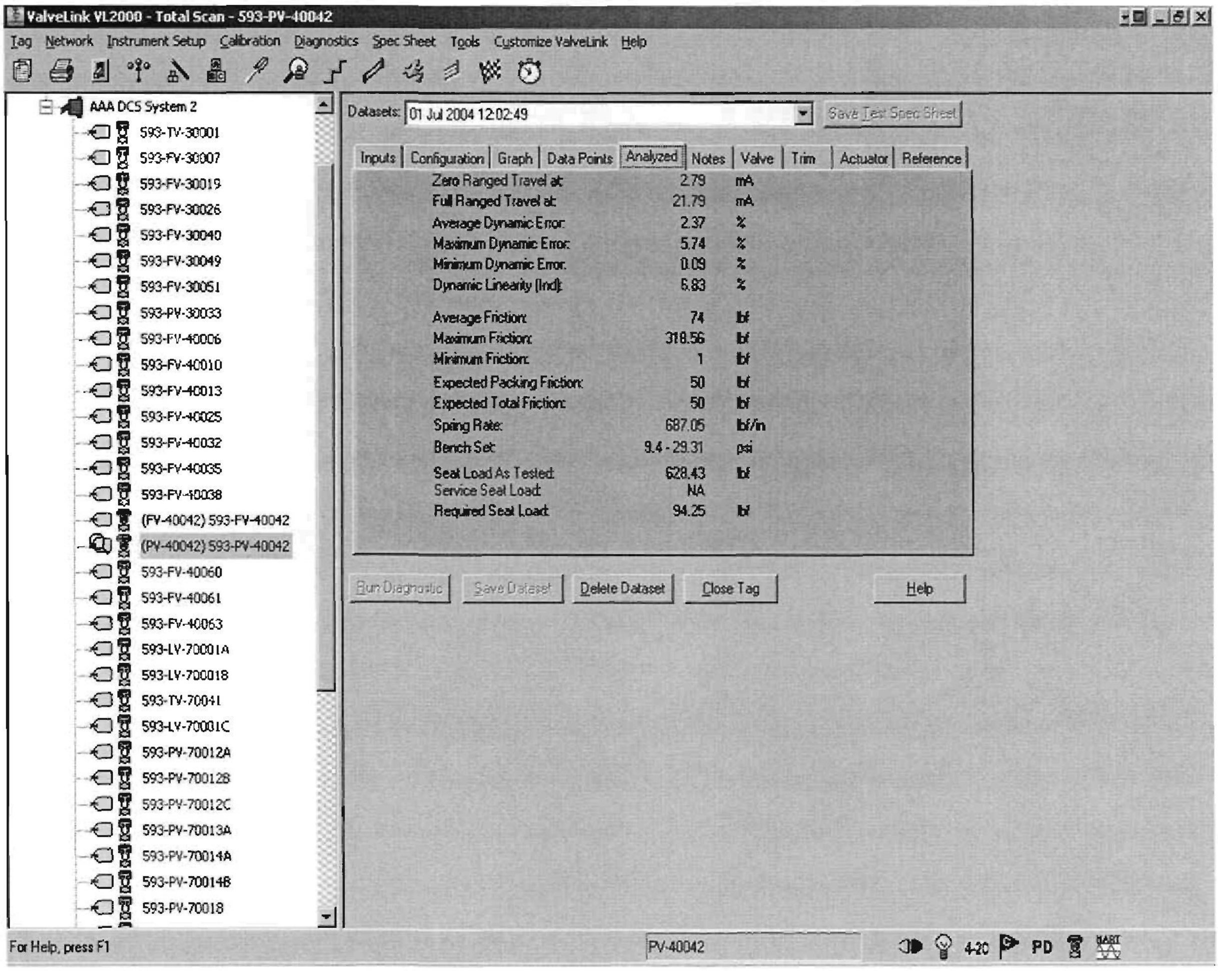


Figure 13: Typical Valve Signature (Stem travel against time)

In figure 14, more valve signature details are displayed. As shown in the screen display, the amount of signal (current) required for full ranged travel and zero ranged travel of the valve stem can be determined, as well as the dynamic error associated with these.

Armed with this information, the control system engineer can then troubleshoot any problem with valve response or make adjustments to the valve configuration to compensate for problems such as friction, spring effect, bent stem etc until appropriate time for maintenance.



Datasets: 01 Jul 2004 12:02:49

Zero Ranged Travel at:	2.79	mA
Full Ranged Travel at:	21.79	mA
Average Dynamic Error:	2.37	%
Maximum Dynamic Error:	5.74	%
Minimum Dynamic Error:	0.09	%
Dynamic Linearity (Ind):	6.83	%
Average Friction:	74	lbf
Maximum Friction:	318.56	lbf
Minimum Friction:	1	lbf
Expected Packing Friction:	50	lbf
Expected Total Friction:	50	lbf
Spring Rate:	687.05	lbf/in
Bench Set:	9.4 - 29.31	psi
Seat Load As Tested:	628.43	lbf
Service Seat Load:	NA	
Required Seat Load:	94.25	lbf

Figure 14: Valve Signature Analysis Information

In an interview with Louw et al (2007), credence was lent to the fact that the ATR plant technicians are now able to monitor the health and the integrity of their instruments and valves. Before, this was difficult as the instruments would have to be inspected every time there was planned or opportunity plant shutdown to ascertain the health of the field devices. But now, with the help of asset management integrated with the control system, they are able to know which valve or instrument needs maintenance. These devices which are the Fieldbus type can report conditions directly to the asset management system. These conditions can range from potential problems such as hardware failures within the device, loop problems, and misconfigured parameters, to proactive reporting of upcoming maintenance needed. Besides, the approach to maintenance, according to them, is more improved and standardized.

In N-Butanol plant case study, integrated control and asset management has really enhanced the way the field equipment and valves are utilized. Figure 15 shows a pie chart of all the assets in the plant.

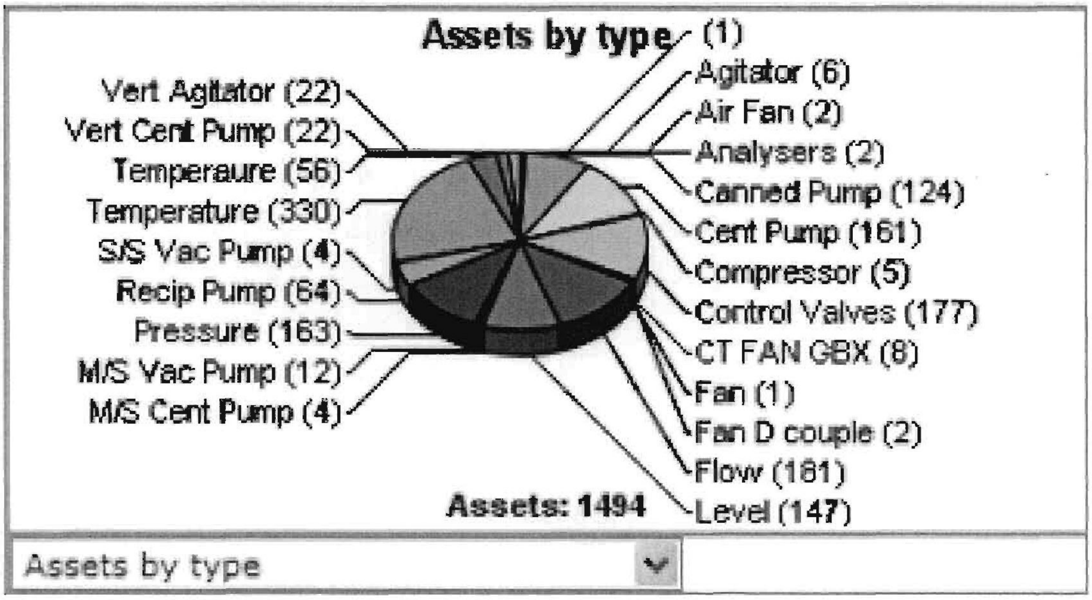


Figure 15: N-Butanol plant asset by type

To manage these assets, which are many, a technician does not have to check them one by one; rather through integrated control and asset management, each device reports its own status to the asset management and if there a deviation an alert is generated. In figure 16, the active alerts

Figure 16: Active Alerts received according to duration

yed. A red sector means a 'no communication' alert, a yellow sector represents an abnormal situation alert while a purple sector means maintenance needed.

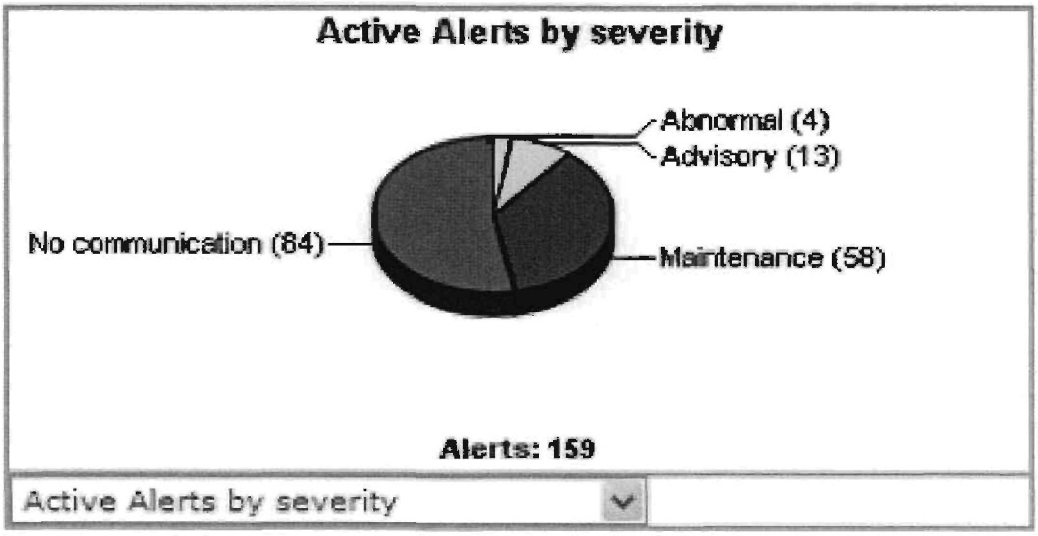


Figure 17: Active Alerts received according to Severity

With the greater confidence in integrated control and asset management, an engineer or technician needs only act based on this information; thus enhancing the way he performs his job. Besides, the number of personnel required would be reduced.

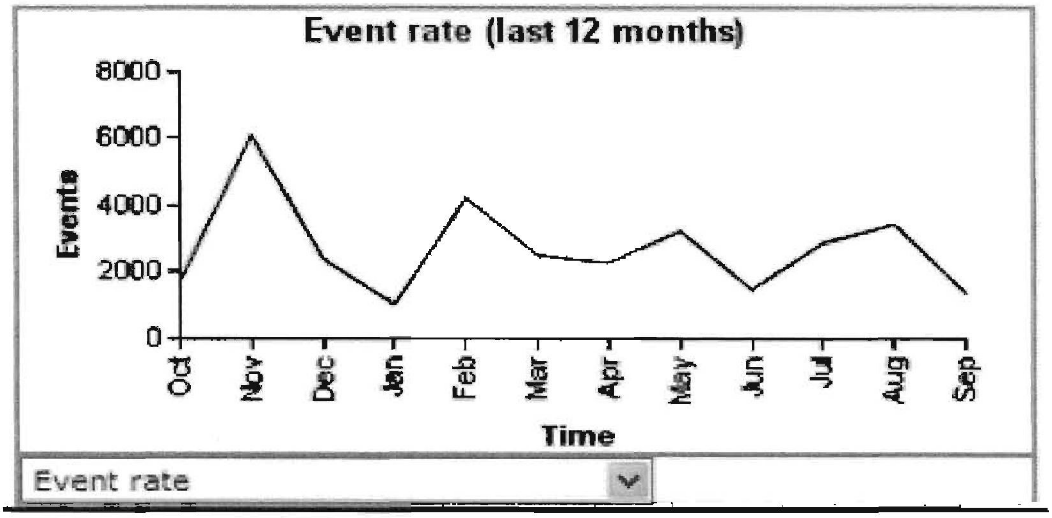


Figure 18: Event rate over a 12-month period

The event rate over a 12-month period is shown in figure 18. An event is an occurrence in the performance of field assets that requires an operator, engineer or technician's attention. Most of the events displayed above are due to alarms.

4.3 ICAM Limitations

Despite the so many benefits highlighted in this discussion, some challenges and limitations were discovered in the implementation and use of integrated control and asset management in these plants.

1. Integrated control and asset management relies on electronic communication. Therefore, mechanical failures in valves or instruments may not be detected if the electronic communication itself is faulty. Though there will be an indication that something is wrong or the reading is not correct, it will not be able to tell what it is if it is a mechanical failure.
2. A plant's culture and criticality can reduce the confidence in ICAM. Current engineers and technicians prefer to work with what they know and ICAM is a sophisticated technology. So, if the technician feels the technology is complex, though it ought to enhance the performance of his job, he might go back to the old ways of doing things, thus reducing value added. The engineer who built the system is not the man who runs it. According to Louw et al (2007), they still prefer to 'run to failure' regardless of the predictions and suggestions of the asset management because of the risk involved. The ATR plant, for

example, is at the heart of Sasol One site, and the plant's unavailability means the unavailability of the major plants in Sasol One site including the methanol plant, rectisol plant, N-butanol plant, Sasol wax plant, Natref, Ammonia plant, etc. Therefore, the risk is so enormous that they cannot take any chances. They prefer to spend money on overhauling of the critical valves, for instance, every time there is opportunity maintenance, even if nothing is wrong with the devices as suggested by the condition monitor, than to lose the plant and incur heavier losses. In essence, maintenance is not completely done according to the asset management predictions and suggestions.

3. It is difficult to implement integrated control and asset management in older Sasol plants until the plants get to a point where the devices need to be replaced. This is due to the enormous cost involved. In other words, it is financially prohibitive. These older plants have valves and instruments that are not SMART capable, making it difficult to deploy ICAM because ICAM cannot function with filed devices that are not SMART capable or that are not intelligent.
4. Initially, management was skeptical about the 'integrated control and asset management' technology. But with the success recorded in N-Butanol plant implementation, management confidence has improved.
5. The ICAM technology is only as good as the control system software a plant uses. The meaning of this is that much cannot be derived from ICAM if the control system software does not support it. Thus, the type of control system software to be used must be taken into consideration when thinking of deploying ICAM technology.
6. ICAM generates a lot of data. Sometimes, it unlocks data that is resident in the control system, thus giving more data. Currently, there is a difficulty in analyzing and interpreting this data, particularly by the technicians. There is, therefore, a need to raise the skill level of the technicians to be able to make the most out of this data.

CHAPTER 5

5.0 ICAM implementation in the World

In chapter four, an analysis and discussion of the results obtained was presented. In the N-Butanol and ATR plants case studies considered, it was shown that integrated control and asset management does indeed help optimize the running of the process plants through predictive technologies and it increases plant uptime. The investigation was, however, limited to instruments and valves.

In this chapter, I want to authenticate the claim that integrated control and asset management help optimize the way a plant is operated. The evidences in chapter four have confirmed this; however, there are documented records of successes in the use of integrated control and asset management in other plants in the world.

Petroflex, a synthetic rubber plant in Brazil (Anon 2005), claimed to have recorded

- 15% reduction in variability and
- 10% cost savings in steam usage, contributing about $20K per year to the bottom line

The gains occurred as a result of implementing integrated control and asset management. Before then, the challenge was that its Cabo de Santo Agostinho plant located in Brazil with a capacity of 125 million tons/year and producing about 28 product varieties was experiencing higher than acceptable process variability. The corporate goal of becoming a six sigma supplier of synthetic rubber was largely unmet due to limitations of the legacy control systems. The corporate business strategy required adopting a continuous permanent modernization process for the Cabo plant. The challenge was to achieve a world class, six sigma product quality status with reduced process variability and reduced costs. When Emerson process management conducted a plant study, it was discovered that several valves were unsuitable to meet the process demands. Besides, process data was not being gathered for analysis and improvement. With the implementation of integrated control and asset management, process variability on a distillation column decreased from 15-20% to less than 5% and contributed to a 10% cost savings in steam usage, thereby adding about $20,000 per year to the bottom line.

With the implementation of integrated control and asset management, Lake Charles refinery (Anon 2005) of Pelican Refining (USA) recorded the following benefits

- Restoration and modernization of a decommissioned unit which increased refinery capacity by 5,000 bpd
- 80% annual return on automation investment
- 75% savings in time for implementing a modernization project compared to traditional control system

Before implementing ICAM, the challenge then was to increase refinery capacity with the least investment; transform an archaic 25 year old, pneumatic and relay logic technology driven refinery to leapfrog into the latest generation, highly automated digital plant, and achieve the target increases in production with lower costs, with the least downtime, and that too by using existing plant resources. However, after implementation of ICAM, the plant not only became modernized, significant benefits were realized.

At Goldschmidt Chemical, Mapleton, ILL, (**Asset Management Prevents Lost Production, 2000**) the company had no way of maintaining information on its field instrumentation until the implementation of ICAM. Also, up to 70 transmitters had been lost due to malfunctioning temperature reading. After implementing ICAM, information about all those instruments' conditions began flowing into the control engineer's personal computer (PC) and was stored in the asset management system database. Besides, engineers can configure and calibrate all HART-supported devices in the field from their offices. Information for specific instruments that are to be calibrated is downloaded from the database. Once the calibration tests have been completed in the field, the results can be uploaded to the engineer's PC for review and possible action. The results thus become part of each instrument's permanent record, so the engineer can check on previous calibrations of a given instrument. In addition, the vast amount of information generated by the SMART field devices is used to reduce maintenance costs and reduce expenses.

The following particular case study was culled from **Asset Management Prevents Lost Production (2000)**.

"A valve was leaking in an area of the company's process. A maintenance crew member already had drawn a replacement from stock and was preparing to shut down that part of the process to make a switch. The control engineer suggested a closer look using the asset management system.

It became apparent that even though the valve indication was closed, the system revealed a substantial amount of air pressure still in the actuator. The valve was not leaking and did not need to be replaced. In 10 minutes, the problem was corrected by recalibrating the positioner. This was done from the control engineer's office. Without the asset management system, maintenance would have shut down the process for four or five hours to replace a valve that was in good working condition. The cost would have been more than that of the replacement valve and the crew's time; it would have included several thousand dollars per hour of lost production time."

At Eka Chemicals located at Maastricht, the Netherlands, operational savings had been recorded through the use of integrated control and asset management system. The ICAM system has enabled a reduction in maintenance costs and unscheduled shutdowns whilst also improving efficiency and control. "We have reduced our maintenance costs by 10-20 percent," (**PlantwebNews, 2007**). This has been accomplished by utilizing the remote diagnostic and calibration capabilities of the field instrumentation, coupled with the asset management software. *"During a particular process problem, for example, the control system was interrogated, and two control valves were identified as being at the root of the problem. The asset management software was used to recalibrate the valves, which solved the problem. Previously it would have taken a considerable time to identify and rectify this type of fault." Also, If there are any control problems outside of normal working hours, the engineer just dials in from home over a modem to troubleshoot. Often this means a trip to the plant is not required".* Since this installation, unplanned shutdowns have been reduced by 10 percent. We have been able to achieve this by closer monitoring of our processes. We have set conditional and deviation alarms that warn us of problems, and we can then take action to prevent a shutdown. This has also made our plant safer. Our levels of control have improved significantly, and we now have improved batch consistency and an increase in production levels."

As another case history, DSM Anti-Infectives, located in Delft, the Netherlands, reported that it has recorded significant operational savings through the use of Emersonprocess management asset management system, an architecture based on integrated control and asset management technology. The savings have been made by utilizing the predictive capabilities of technology which include accessing the online diagnostic capabilities of the intelligent field devices networked throughout the plant. The information that is provided enables a move towards predictive maintenance, a more effective maintenance strategy that makes it possible to limit the potential for unplanned shutdowns and extend the time between planned shutdowns.

The DSM anti-infectives maintenance supervisor for electrical and instrumentation remarked as follows: *"we use asset management system to perform maintenance activities on our instrumentation. This has brought us significant savings. Before our technicians go out on site to look at a transmitter, they perform diagnostic checks from the asset management system operator station. This means that they know whether the transmitter in question is faulty and what exactly is wrong with it. I believe this ability enables us to spend 50 percent less on maintenance than we would have done had we been operating a more traditional plant."* **(Chemical_SuccessStories_DSM01, 2007)**.

At BP Chemicals butanediol (BDO) plant located in Lima, Ohio, an implementation of integrated control and asset management system through a combination of SMART instruments, Foundation fieldbus communication protocol and asset management software has brought about increased reliability and reduced cost. (**Controlling Processes via Fieldbus -- Increasing reliability and reducing costs, 2007**).

Control loop configuration is now much easier. Also, there are as many operator benefits such as the operator knowing when a valve has been poorly tuned or just sluggish, such that he can make the appropriate compensation while controlling the process pending the time the problem is fixed.

The Eastman Chemical Company located in Sokolov site, Czech Republic has recorded 30 percent cut in cable costs and reduced the time taken to commission process loops by using Emersonprocess PlantWeb digital plant architecture (based on integrated control and asset management technology) to re-automate one of the acrylic acids plants on their Sokolov site in the Czech Republic. FOUNDATION fieldbus and HART digital communications technologies (key components in ICAM) are used to communicate with the 900 new field instruments, enabling further savings to be made over the lifetime of the plant.

According to the company, the extensive use of FOUNDATION fieldbus digital communications has reduced the average cable length per device to 49m, as opposed to the 220m required for conventional instrumentation. This has reduced cable costs by approximately thirty percent. The use of FOUNDATION fieldbus digital communications also enabled control loops to be commissioned faster than planned. During commissioning on one plant, for example, 175 I/O were brought on line in five days, nine days quicker than planned.

The BP petrochemical facility at Grangemouth, Scotland, has reported $2.5 million annual savings owing to integration of asset management system with the control system. A sum of $1.5 million energy savings has been realized from utilities optimization, and another $1 million benefit gained due to 4 percent increase in plant throughput from its KG Ethylene optimization application. The asset management system has also enabled BP to achieve consistent plant operation, improve control of daily key performance indicators KPIs) and enhance the planning process through improved equipment selection. (**Chemical_SuccessStories_BP-Grangemouth01, 2007**).

According to BP's lead control engineer - Commercial & Optimization Team, Simon Lopez, *"the optimizer has been instrumental in pushing the operating boundaries of the plant, specifically the compressor trains that were a major constraint on throughput. By selecting the loading on each of the operating cracking furnaces, the asset management system optimizer is able to achieve improved product yields from the available feed stocks and, based on the product prices on the day, targets the optimal product spectrum. Since the optimizer is closed loop, we are able to achieve maximum benefit with no delay in the implementation of the set points."*

An important consequence of this is that the plant operators and management, who see the asset management system as an integral part of the plant control system and operating procedures, have embraced the technology.

The case studies above show the many benefits of the technology of integrated control and asset management. The situation in Sasol as articulated in this research work is no different from the different case studies discussed above. In fact, I venture to say that while the each of the case studies recorded success in only some areas, Sasol's success is somewhat all-encompassing. Sasol's case study combines most if not all of these benefits.

From the foregoing, it can be fairly concluded that Sasol practice vis-à-vis operations is world class; world class in the sense that Sasol is not behind most other petrochemical (and non-petrochemicals) industries in terms of process operations. However, looking at the SAMI model once again, Sasol still has a long way to go to achieve operational excellence. Currently, the company is in stage two whereas the target is stage five. Like Sasol, many other top-notch countries the world over are still within stage two and three.

Having successfully implemented stage two of the SAMI model to which integrated control and asset management is pivotal, Sasol is set to move to higher stages. Again, integrated control and asset management is the key to successful implementation of stage two.

The success records discussed in this chapter have authenticated the fact that integrated control and asset management does indeed give rise to optimized process operation.

CHAPTER 6

5.0 CONCLUSIONS AND RECOMMENDATIONS

In this research work, integrated control and asset management (ICAM) technology has been discussed. It involves incorporating asset management functionalities with the control system. While the control system performs the process control functions, the asset management functionalities monitor the condition of both the process and the assets with ultimate goal of optimization their performance.

An investigation of integrated control and asset management implementation was conducted in two plants in Sasol, the ATR and the N-Butanol, and the results showed that tremendous success has been recorded in the use of ICAM in these plants. Both the monetary and non-monetary benefits that ICAM offered were documented. The success recorded supports the initial hypothesis that ICAM enhances asset performance, thus giving rise to increased uptime and early fault detection.

This work has thus added to the pool of evidence supporting the claim that optimized process operation can be realized by integrated control and asset management.

Integrated control and asset management is hereby recommended for deployment in plants that still use the old technologies. However, such an implementation is recommended only when the assets approach their replacement period, otherwise it would be financially prohibitive.

Also, companies planning to embark on building new plants should consider integrated control and asset management right from the onset. This will not only assure optimal process operation, but will also enable easier and proactive maintenance.

Lastly, some limitations were discovered in the course of this research work in the capabilities of integrated control and asset management, for example the type of control system software used in the plant places a constraint on the performance of the asset management system. If the control software does not support it or partially supports it, not much can be realized from the asset management system.

Further research work in this field should investigate how these limitations could be overcome in future designs and implementation.

LIST OF REFERENCES

ANON. The SMART Refinery. 2004. Hydrocarbon Engineering Electronic Journal. http://www.emersonprocess.com/home/library/articles/hycbengr/hycbengr0404_smartrefinery.pdf Date of Access: 5 Mar. 2007

ANON. 2005. Petroflex Gains World Class Product Quality for Synthetic Rubber Plant with Emerson's Plantweb Architecture. http://www.documentation.emersonprocess.com/groups/public_groupmarcom/documents/qbr/chmqb0512e_petroflex.pdf?&xBusinessUnit=Systems%20&%20Solutions Date of Access: 27 May. 2007

ANON. 2005. Pelican Refining Increases Lake Charles Refinery Capacity with Emerson's Plantweb Architecture and Foundation Fieldbus. http://www.documentation.emersonprocess.com/groups/public_groupmarcom/documents/qbr/refqb0512e_lakecharlesrefinery.pdf?&xBusinessUnit=Process%20Systems Date of Access: 27 May. 2007

ANON., 2006. (From Wikipedia, an online encyclopedia). http://en.wikipedia.com. Date of Access: 12 Sept. 2006

How Sensors Work. 2006. (An online publication on HART digital Protocol) http://www.sensorland.com/HowPage045.html Date of Access: 12 Aug. 2007

Asset Management Prevents Lost Production. 2000. http://plantweb.emersonprocess.com/customer/chemical_includes/technical_articles/GoldschmidtChemical.pdf Date of Access: 5 Aug. 2007

BECKER, W., OTT, B., STALLOCH, G. 2006. Stepping Up Condition-Oriented Maintenance of Technical Systems in Underground Gas Storage Facilities. (23RD World Gas Conference), Amsterdam, 2006. pp 1-9 http://igu.dge.dk/html/wgc2006/pdf/paper/add11635.pdf Date of Access: 28 Sept. 2006

BENGSTON, M. 2004. Condition-based Maintenance System Technology- Where is the Development Heading? (Euromaintenance 2004- Proceedings of the 17th European Maintenance Congress, 11th – 13th of May, 2004, AMS (Spanish Maintenance Society), Barcelona, Spain, B- 19.580-2004

BERRA, J. 2003. 20 Minutes with John Berra. (HART Communication Foundation Publication). pp 1-5

BOCK, H.G. 2004. Dynamic Process Optimization. (A tutorial course on Non-linear optimization and Optimal Control. University of Hiedelberg). Oct 2004. [http://www.iwr.uni-hiedelberg.de/~agbock/ Date of access: 30 Sep. 2006

BP Canada Energy is Named 2006 Hart Plant of the Year. 2006 http://www.automationworld.com/view-2657 Date of Access: 26 Dec. 2006

BUNKS, C., MCCARTHY, D., AL-ANI, T. 2000. CBM of Machines Using Hidden Markov Models. Journal of Mechanical systems and Signal Processing, 14(4): 597-612, April

Chemical_SuccessStories_BP-Grangemouth01. 2007. http://plantweb.emersonprocess.com/customer/Chemical_SuccessStories_BP-Grangemouth01.asp Date of Access: 25 Sept. 2007.

Chemical_SuccessStories_Eastman01. 2007 http://plantweb.emersonprocess.com/customer/Chemical_SuccessStories_Eastman01.asp Date of Access: 25 Sept. 2007.

Chemical_SuccessStories_DSM01. 2007. http://plantweb.emersonprocess.com/customer/Chemical_SuccessStories_DSM01.asp Date of Access: 25 Sept. 2007.

CHEN, D., TRIVEDI, K.S. 2005. Optimization for Condition-based Maintenance with Semi-Markov decision Process. Journal of Reliability and System safety, 90:25-29, December

CIARAPICA, F.E., GIACHETTA, G. 2006. Managing the Condition-based Maintenance of a Combined-Cycle Power Plant: An Approach Using Soft Computing. Journal of Loss Prevention in the Process Industries 19 (2006):316-325, June

CLAASSEN, J., DOONAN, P., HEERALALL, V., LALA, A. 2007. Verbal communication with the N-Butanol/AAA plant engineering manager, reliability engineer, and control system engineer. Sasol Midland site, Sasolburg.

Controlling Processes via Fieldbus -- Increasing reliability and reducing costs. 2007 http://plantweb.emersonprocess.com/customer/Chemical_TechnicalArticles_BPChemicals01.asp Date of Access: 10 Sept. 2007

HART Communication Foundation. 2006
http://www.hartcomm.org/ Date of Access: 20 Oct. 2006

HIMMELBLAU, D.M. 1978. Fault Detection and Diagnosis in Chemical and Petrochemical Processes. Amsterdam: Elsevier Scientific Publishing. 1-16 p

HOWELL, A., HARRISON, K., DHOLE, V., SIM, W. 2002. Engineering to Business: Optimizing Asset Utilization Through process Engineering. Journal of Measurement and Control, 54-63, September. http://www.cepmagazine.org. Date of Access: 13 Oct. 2006

HULSHOF, H.J.M., NOTEBOOM, J.W., WELBERG, P.G.M, BRUIJN, L.E. 2004. Improved Plant Availability by Advanced Condition-based Inspections. International Journal of Pressure Vessels and Piping 81(2004):491-497, April

JACQUOT, R.G. 1981. Modern Digital Control System. New York: Marcel Dekker Inc. 1-9, 215-241 p

JARDINE, A.K, LIN, D., BANJEVIC, D. 2006. A Review on Machinery Diagnostics and Prognostics Implementing Condition-based Maintenance. Journal of Mechanical Systems and Signal processing, 20:1483-1510, Jan

KEYSER, J., STAPLES, J. 2006. Verbal communication with then acting production manager and optimization manager for the ATR plant. Sasol One site, sasolburg.

LATEGAN, W., HUMPHRIES, R., NIERKERK, V.J., MABITSELA, S. 2007. Verbal communication with Sasol R&D engineering services control systems engineers. Sasol One site, Sasolburg

LEBOLD, M., THURSTON, M. 2004. Open Standards for Condition-based Maintenance and Prognostics Systems, Applied research laboratory, Penn State University, USA

LEE T.H. ADAMS, G.E., GAINES, W.M. 1968. Computer Process Control: Modeling and Optimization. New York: Wiley. 171-191, 310-341 p

LOUW, J., HEUNIS, F. 2007. Verbal Communication with ATR Instrument Foreman and Instrument Supervisor. Sasol One site. Sasolburg.

LUYBEN, W.L. 1980. Process Modeling, Simulation and Control for Chemical Engineers. 2nd Ed. New York: McGraw-Hill. 11-25 p

MARSEGUERRA, M., Zio, E., PUDOFILLINI, L. 2002. Condition-based Maintenance Optimization by means of Genetic Algorithm and Monte Carlo Simulation. Journal of Reliability Engineering and System Safety, 77:151-166, April

MCMILLAN, G.K. 1994. Tuning and Control Loop Performance. 3rd Ed. North Carolina: Instrument Society of America. 49-100, 179-202 p

MITCHELL, J.S. 1998. Five to ten year vision for CBM. (At ATP Fall Meeting – Condition Based Maintenance Workshop. USA, Atlanta, GA, 1998, Powerpoint Presentation). http://www.atp.nist.gov/files/3 Date of Access: 14 Jan. 2007

MOYA, C. C., VERA, J. C. H. 2003. Evaluation of Condition Based Maintenance through Activity Based Cost, "Maintenance Journal", Vol. 16, No. 3, 2003.

OLSEN, T., RINEHEART, N. 2006. Process Performance Through Critical Control Loop Optimization, Fisher Controls International Inc, http://www.emersonprocess.com Date of Access: 22 Mar. 2007

PARKER, S.P. 1984. Optimization Theory. (In Encyclopedia of Science and Technology. 6th Ed. New York: McGRAW-Hill. 1214-1216, 1391 p)

PETERSON, S.B. 2005. Assessing Plant Potential for Asset Management. (Electronic Journal of Strategic Asset Management Inc. publication) pp 1-5 http://www.samicorp.com/Main%20Menu/publications/publications.pdf/articles/bradpeterson/assess_plant_potential.pdf Date of Access: 5 Mar. 2007

PETERSON, S.B. Defining Asset Management. (In SAMI (Strategic Asset Management Incorporated) publication) http://www.samicorp.com/Main%20Menu/publications/publications_.pdf/articles/bradpeterson/defining_assetmanagement.pdf Date of Access: 5 Mar. 2007

PIATER, E. 2006. Verbal Communication with Sasol Infragas Coach. Sasol One site, Sasolburg.

Plantweb News. Emerson technologies reduce shutdowns, increase production, and improve product quality. 2007 http://plantweb.emersonprocess.com/customer/Chemical_SuccessStories_EkaChemicals01.asp Date of Access: 5 Aug. 2007

RASMUSSEN, J.R. 2003. A Plant Asset Management System for Hydroelectric Turbine/generators.(At Iris Rotating machinery Conference Paper, Santa Monica, CA). 1-5 http://www.irispower.com/newsite/techpapers/Years/2003/A%20PLANT%20ASSET%20MANAGEMENT%20SYSTEM%20FOR%20HYDROELECTRIC%20TURBINE%20GENERATORS.pdf Date of Access: 15 Aug. 2006

REEVES, T. 2006. Analyse This. Journal of PUMPS & SYSTEMS. Pp 1-6. May [www.pump-zone.com]

SAMI Model. 2006. http://www.samicorp.com Date of Access: 10 Dec. 2006.

SCHNEIDER, J., GAUL, A.J., NEUMANN, C., HOGRAFER, J., WELLBOW, W., SCHWAN, M., SCHNETTLER, A. 2006. Asset management Techniques. Journal of Electrical Power and Energy Systems, 28(2006):643-654, June

SMART, J.D. 2002. Fieldbus Improves Control and Asset Management.
Journal of Hydrocarbon Processing, 2002: 55-57, Jan

SMITH, A.E., COIT, D.W., LIANG, Y. 2002. A Neural Network Approach to CBM: Ground Transportation Vehicles.

TAYLOR J.H., SAYDA A.H. 2005. An Intelligent Architecture for Integrated Control and Asset Management for Industrial Processes. http://www.unb.ca Date of Access: 14 Jun. 2006

WETZEL, R. 2004. Condition Monitoring Within Enterprise Information Systems. (Article of Maintenance Technology)
http://www.mt-online.com/articles/12-99im.cfm Date of Access: 11 Nov. 2006

WHITE, D.C. 2003. Creating the SMART Plant. Hydrocarbon Processing Journal. pp 41-50, Oct. http://www.easydeltav.com/news/viewpoint/HP1003.pdf Date of Access: 5 Feb. 2007

WILSON, A. 2002. Asset maintenance Management: A Guide to Developing Strategy and Improving Performance. New York: Industrial Press Inc. 3-36, 59-92, 165-190, 291-324, 713-744, 745-806 p

WOLMARANS, A. 2007. Verbal Communication with the Auto-Thermal Reforming (ATR) plant manager. Sasol One site, Sasolburg

YAM, R. C. M., TSE, P. W., LI, L., TU, P. 2001. Intelligent Predictive Decision Support System for Condition-Based Maintenance, "International Journal of Advanced Manufacturing Technology", 2001, Vol. 17, Issue 5, pp. 383-391.

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LIST OF ACRONYMS

ATR:	Auto-Thermal Reforming
CMMS:	Computerized Maintenance Management System
DCS:	Distributed Control System
FSK:	Frequency Shift Keying
HART:	Highway Addressable Remote Transducer
ICAM:	Integrated Control And Asset Management
ISO:	International Standards Organization
PLC:	Programmable Logic Controller
RTU:	Remote Terminal Unit
RUL:	Remaining Useful Life
SAMI:	Strategic Asset Management Inc
SCADA:	Supervisory Control And Datal Acquisition
SMART:	Self Monitoring Analysis and Reporting
SPECA:	Speckle Images Correlation Analysis
SSBAC:	Sasol Synfuels Butanol and Acrylate
STAR:	Sasolburg Total Asset Reliabilty