Data Trending to Support Ageing and Life Extension (ALE) in the United Kingdom Continental Shelf (UKCS) Oil and Gas Industry

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The Health and Safety Executive (HSE) instigated their Key Programme 4 (KP4) to look into the problem of Ageing and Life Extension (ALE) of the United kingdom Continental shelf (UKCS) oil and gas infrastructure in hostile environments such as the North Sea. Two key findings of the KP4 programme were that:

Better use could be made of data trending to support ALE decision making;

UKCS Oil & Gas sector had not identified leading (Key Performance Indicators) KPIs suitable to support ALE decision making.

As part of the KP4 programme, the Health and Safety Laboratory (HSL) looked at the apparent lack of data trending performed in the UKCS oil and gas industry, in particular, trending used to support ALE. HSL discussed data trending issues with HSE offshore specialist inspectors who undertook KP4 work, oil and gas engineers and oil and gas specialist contractors involved with data trending.

HSL identified issues associated with the collection, storage and management of data that could impede the implementation of data trending in the UKCS oil and gas industry. The available data covered a range of factors such as equipment performance, maintenance and production factors.

Industry uses KPIs as a metric for the measurement of key factors such as maintenance, performance and equipment reliability. KPIs that indicate the current condition of equipment and systems can be said to be lagging indicators with regard to ALE. ALE is focused on the future condition of equipment and systems, and the trending of lagging KPIs enables the future condition of the asset to be estimated. Therefore, trending can be said to convert lagging KPIs into leading KPIs and it is these leading KPIs that can directly support ALE decision making.

This paper presents and discusses the key findings of HSL's work, such as issues surrounding data collection, management and use of data, and how such factors can affect the uptake of data trending. It suggests a number of KPIs that can be trended to support ALE, and presents two examples of trending KPIs. It also discusses potential problems with analysis methods, suggesting that while basic trending of performance measures such as equipment breakdown frequency can be trended by engineers, there are pitfalls associated with trending that need to be understood.

It is concluded that sufficient data exist that can be trended to support ALE decision making and that a better understanding of data trending requirements can help the industry take full advantage of the resultant benefits.

1. Introduction

In July 2010 HSE's Offshore Division (OSD), now Energy Division (ED), launched Key Programme 4 (KP4) targeting Ageing and life Extension (ALE). The programme aimed to improve the management of the risks associated with the ageing nature of the United Kingdom Continental Shelf (UKCS) oil and gas industry.

KP4 involved raising the profile of ALE in the UKCS oil and gas industry through a series of targeted inspections, both onshore and offshore, using specialist templates. The KP4 inspections aimed to facilitate improved management of ALE and to identify and promote current good practice.

Data trending and leading ALE KPIs were areas identified during the KP4 programme where improvements could be made. These improvements could help the industry turn its existing data into useful knowledge that would support ALE decision making.

This paper presents work undertaken by the Health And Safety Laboratory (HSL) to look at data trending performed in the UKCS oil and gas industry and identify areas where improvements could be made to encourage the take up of data trending to better support ALE decision making as part of the KP4 programme of work. The aim of this work was to gain a snapshot of the extent of data trending performed in the UKCS oil and gas industry, and to suggest benefits that data management and trending could bring to the industry.

2. Benefits of data collection and trending

In an ideal world, organisations need to know what equipment and systems they have, what the current condition is, and how this condition is changing over time. Data collection and trending have many benefits that can contribute to ALE decision making, asset integrity management and production management. Figure 1 depicts a data management and trending approach, which could help target resources consistently, and improve production efficiency as well as safety. The methodology is described below:

1. The first step to facilitating data analysis and trending is to collect relevant data from multiple sources, all stored in a common repository that is readily accessible by those who need to use the data;
2. Trending data in this case refers to the analysis of equipment, systems and people performance, which can provide a number of benefits;
3. Trending gives knowledge of past, present and future condition and/or performance of equipment, systems, maintenance capability and production. Trending can give advanced warning of when equipment and systems could fail. Trending can

identify circumstances where further investigation is required to identify underlying ALE issues such as, creeping change (Goff et al, 2015), obsolescence or skills shortage in relation to each system or item of equipment;

4. This knowledge can lead to improved maintenance productivity through efficient, short, medium and long term planning of maintenance activities;
5. Efficient planned maintenance reduces unplanned equipment downtime due to unexpected failures. This leads to improved equipment availability;
6. This can lead to efficient use of resource, for example, man hours and spare parts;
7. An example of efficient maintenance planning specific to ALE management at UKCS oil and gas installations is the increased availability of bed space at the installation;
8. This can lead to improved scheduling for major replacement and/or upgrade projects;
9. Trending contributes to improved management of both ALE and Asset Integrity Management (AIM), and hence installation productivity and longevity.

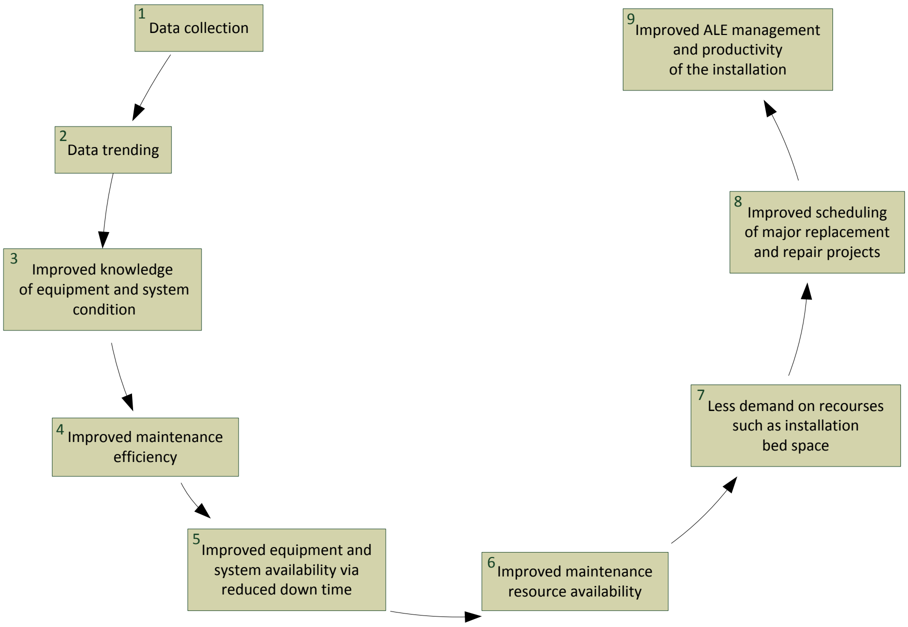

Figure 1- Benefits of collecting and trending data in the UKCS oil and gas industry

3. Data collection and storage

KP4 established that data associated with maintenance activities are typically recorded in text and numeric data fields within a Computerised Maintenance Management System (CMMS), which is typically based on a common database engine such as Oracle.

CMMS's can be accessed by third party analysis tools, which can import and export data in an Open DataBase Connectivity (ODBC) compliant format, although these operations require specialist knowledge of such systems. The two prevalent CMMS tools used in the UKCS oil and gas industry are SAP and Maximo.

The primary use of the CMMS is to generate work orders from stored data and to record the work activity outcomes. It is then up to the relevant engineers, Technical Authorities (TAs) and managers to interrogate the CMMS to support their decision making processes. Those responsible for collecting data, including technicians, engineers, TAs, and specialist contractors, input data into the CMMS. Data can be entered and accessed either manually by persons with the relevant permission, or automatically by other software tools that are designed to work with the CMMS. Like all database tools, the CMMS stores data in fields, the size and format of which are predetermined by the supplier and the users' IT department.

Specialist contractors are likely to use specialised equipment that often has its own storage capability. For example, some handheld data logging devices are capable of performing a basic analysis on their stored data for immediate display. This data are not generally downloaded into the CMMS, which is not designed to perform analysis on the stored data. Data trending needs to be performed using third party specialist software tools.

Data are typically stored using company designated codes. Data fields in a CMMS will typically store, as a minimum, data associated with the following:

- Equipment;
- Site/location – which installation and where on that installation;

- Work type - the type of maintenance/inspection/modification to be performed;
- Work category – safety critical, production critical, routine;
- Priority;
- Assigned to/completed by;
- Fault code/problem code;
- Estimate/actual time to repair;
- Date reported;
- Work start/finish date/status;
- Short text description of work to do/long text description of work and/or outcome;
- Safety Critical Elements (SCEs);
- Live/follow-up required/shutdown/delay.

The raw data from test and inspection tasks are typically embedded in a document linked to the relevant summary report in the CMMS. A summary report of the data usually concludes ‘pass’, ‘fail’, ‘time to repair’, and is stored in the long text field within the CMMS. The summary does not say whether the system is in good or poor condition, thus not giving any indications regarding whether repair or replacement would be a better option. For example, with ‘Ex’ rated equipment used in potentially explosive atmospheres, the maintenance reports the result as either ‘OK’ or ‘defect’. Where a defect is noted, a work order states what work is required for the equipment to be returned to an ‘OK’ state. This level of data storage limits the amount of useful information that can be gained by trending. Any detailed information, if it is stored, is in a separate report, which is not likely to have any known or predictable structure, making useful data difficult to extract.

Non Destructive Testing (NDT) is generally performed by a specialist contractor. NDT reports for vessels or pipes will contain measurements associated with the vessel or pipe wall thickness, but not necessarily the location of the pipe or vessel where the reading was taken. Additionally, the raw data obtained from the NDT activity are not stored or linked to the company’s CMMS. This is generally because the company does not request the raw data; they typically only require the analysis results and any actions to be recorded. Therefore, the specialist contractor will typically store the raw data themselves making it available to the companies if requested. This practice raises issues regarding what happens to the raw data over time, for example, how long the contractor will hold the data, especially if they no longer work for the company whose data they hold. This is one example of a so-called ‘data islands’, i.e. data from specific tasks that are not directly accessible via the company’s IT systems.

3.1 Fault codes

It was found that companies typically use a combination of industry specific fault codes (BSI 2006) and their own fault codes in their CMMS.

The reliability and maintenance data standard BS EN ISO14224 2006 (BSI 2006) defines standard data formats and fault codes and is reported to be widely used in the UKCS oil and gas industry. However, industry specialists say that many companies modify the information formats and the extent of data recorded to suit their requirements or to match existing system use. The use of ISO14224 as a basis for data recording in the UKCS oil and gas industry is good practice and facilitates trending analysis of KPIs and other relevant data providing a consistent benchmark for the industry.

4. KPIs and Data Trending

4.1 What are Key Performance Indicators (KPI)?

KPIs used in the context of the KP4 work give important, or key, information regarding the performance of equipment, systems or processes; in this case important to the short term and long term integrity management of a UKCS oil and gas installation.

4.2 What can KPIs tell us?

KPIs are associated with AIM and ALE, with a degree of overlap between the two depending on how they are implemented within a company. AIM can be defined as managing present and short-term asset integrity requirements; ALE can be defined as managing long-term degradation issues due to ageing assets. It is suggested that the quality of AIM will directly affect the management of ALE; both are important to the continued production until the planned cessation of production date for an UKCS oil and gas installation.

Given the link between AIM and ALE it is suggested that trending requires a multi-tier approach. Trending of maintenance KPIs can identify both immediate issues, such as when to repair or replace, or longer term issues such as whether the time to repair/replace is increasing, and if the repair quality is improving or degrading over time. These trends can identify whether further investigation is required to identify root cause issues associated with ALE such as creeping change (Goff et al, 2015); obsolescence of equipment and spare parts; and shortage of skilled engineers with relevant product experience.

It can be seen that AIM performance can influence ALE decision making by providing relevant information regarding the condition of existing equipment, systems and processes, and indirectly via trending to identify long term issues. The link between AIM and ALE will require careful consideration by those responsible for ALE decision making, to identify ALE specific outcomes.

KPIs associated with AIM are generally considered to be lagging in nature, i.e. they are reactive. Lagging indicators tell us about the current condition of equipment, or process performance, for which there can be many reasons. Lagging KPIs may not identify underlying causes that could affect future performance and they do not predict future performance. However, if a lagging KPI is trended over time then the result is a leading KPI because it can be used to predict future performance, for example, when a system or process is likely to fail its performance measure. This gives much more information in terms of inferences that can be made regarding ALE issues (see table 1 for examples). Additionally, leading indicators facilitate scheduling activities that can have many benefits as described in Figure 1.

4.3 Example KPI that can be used to support ALE

KPIs identified during HSE's KP4 inspection program were mostly associated with AIM, and hence were focused more on the current condition of equipment, systems and maintenance processes rather than on production issues, hydrocarbon leaks and financial issues. It is suggested that trending of relevant KPIs could also benefit these areas but this is beyond the scope of this paper.

Table 1 presents example KPIs taken from HSEs KP4 inspection program, with suggestions for possible outcomes of trending and possible links to ALE issues.

Table 1 – Example KPIs from KP4 inspection program, potential trending outcomes and links to ALE

KPIs identified from KP4 inspection visits	KPI Trending outcome	ALE issues
Equipment/system reliability/availability metrics	Predict when repair/replacement is likely to be required	Obsolescence, maintenance quality, skills shortage, installation bed space
Inhibit/override/bypass records	Identify critical maintenance performance issues	Maintenance quality indirectly affects ALE related work
Incident/near miss investigations	Measures safety culture	A major safety incident could significantly affect the cessation of production date
Process Control System (PCS) alarm rates	Identify unexpected variance in process alarm rates	Change in operating conditions; degraded infrastructure and creeping change; obsolescence
Demand frequencies for Safety Instrumented Systems (SIS)	Identify unexpected variance in SIS demand rates	Change in operating conditions; degraded asset; creeping change, obsolescence of SIS components, skills shortage
Operational Risk Assessments (ORAs)	Measure of maintenance performance over time. Need to identify relevant aspects of ORAs, for example: number of overdue ORAs leading to escalation; number of ORAs satisfactorily closed out on time, number of ORAs linked to SCE etc.	Many possible causes, investigate root causes, could be degradation, obsolescence, skills shortage
Safety Critical Element (SCE) assurance/audit findings	Identify recurrent issues over time	Investigate root causes of recurrent or unexpected SCE failures; creeping change; long term degradation issues
Condition monitoring findings	Identify variance in asset condition over time	Identify asset integrity issues due to degradation, creeping change etc.
Deferred maintenance	Measure maintenance performance over time	Skills shortage (competence), obsolescence, installation bed space (scheduling)

5. Barriers to the uptake of data trending

As part of the trending work performed within the KP4 programme, discussions were undertaken with industry professionals, with UKCS oil and gas operating companies, with specialist support companies and more generally at industry workshop events. Questions were asked about the use of data trending within companies both to support AIM and in particular as a tool to support ALE decision making. It was suggested that data trending was performed on a case-by-case basis where a need was identified for AIM, and that the amount of trending performed varied between companies. It was indicated that at that time almost no data trending was performed to support ALE decision making. On the basis of this information, questions were asked about the barriers to data trending and the issues discussed in this section of the paper are representative of the most common issues raised.

5.1 Background and lack of data

Over the last ten years, some of the original major companies operating in the UKCS have divested assets to smaller companies. Anecdotal evidence suggests that in some cases information associated with these assets regarding equipment, system and maintenance records were lost or failed to be transferred to the new operator. The evidence therefore suggests that many new installation owners have a limited inventory of their newly acquired equipment and systems, which would result in them having to build up this information from scratch as they attempt to apply their own corporate standards.

5.2 Availability

The increased pressure of maintaining and improving profitability in light of dwindling reserves has led to increased focus on short term problems in an attempt to maintain system availability. Additionally many companies do not understand the process and availability requirements of their assets at a sufficiently detailed level to be able to measure and assess performance. In some cases industry wide performance measures for equipment or systems do not exist; for example, there are no published criteria associated with corrosion and minimum allowable wall thicknesses for vessels and pipelines. Generally companies do not know, in detail, the performance levels their equipment should attain.

There have been a number of improvements as companies attempt to manage availability with electronic collection of monitoring data becoming more widely undertaken. However, it is still not evident that this data, typically collected by control room operators and operations personnel, is being managed effectively.

5.3 Relevance of software tools

When engineers request data analysis capability that requires specialist software tools, the company IT departments often specify the relevant software tool requirements without necessarily agreeing the best solution, modules and layout of these tools with the end users, e.g. engineers, TAs and engineering managers. Discussions with industry end users say that this results in a disconnect between their requirements and the IT department; hence the company procures software tools that do not fulfil their requirements, contributing to the common situation where end-users make use of uncontrolled tools such as spreadsheets.

5.4 Lack of information systems integration

To enhance reporting performance, CMMS data is frequently assessed using third party data analysis tools such as Business Objects. It is common practice for the data extracted from the CMMS to be used in isolation from other corporate software. Typically, engineers will request a report that will include a requirement for the data analysis to support their decision making process. The request is subject to an approvals process and is then passed to the IT department, which will produce the requested report. The IT department may misinterpret the engineers' requirements and the resultant report requires reworking, often causing delays in the approvals process (Figure 2).

The lack of information systems integration, easily accessible data and delays in the reporting process result in engineers maintaining their own data sources, e.g. manuals, operating characteristics or availability, and extracting the data themselves from the CMMS. The same engineers then perform their own 'desktop' analysis and produce their own reports, as and when the need arises, typically using spreadsheets and storing the data and analysis locally. This results in 'data islands', where information is not more widely available to users of the company IT systems. Additionally, if the engineer leaves the company, the data is effectively lost. This loss of raw data equates to a loss of knowledge of the installation equipment and any analysis performed; the consequence could be a decrease in availability.

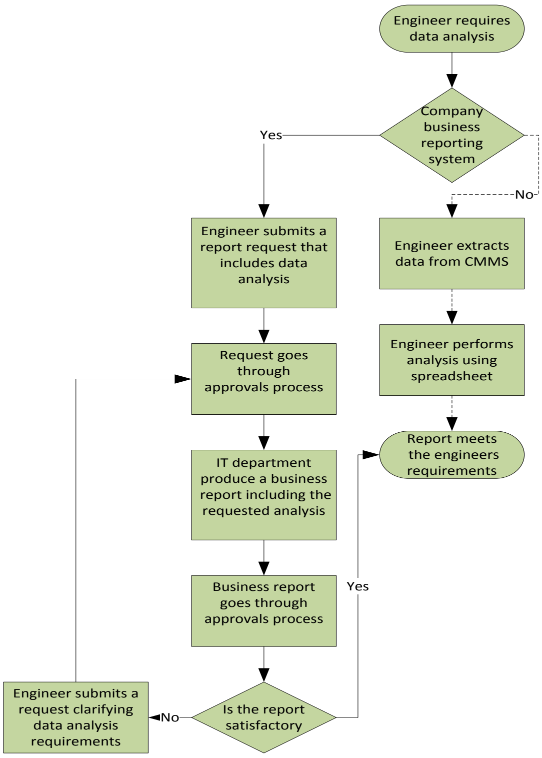

Figure 2. Typical reporting process with short cut alternative

5.5 CMMS limitations

Discussion with industry engineers and contractors suggested that CMMS data fields are often considered too restrictive or ambiguous; therefore, data is often entered in text fields. Data entered this way is likely to vary due to the terminology used by different people; this makes extracting data for trend analysis problematic.

Each person entering data into the CMMS may use different codes and descriptors and not always using all of the required fields in a consistent way.

5.6 Data sharing

At company level, communication between people who have and need information is poor, with disciplines having their own dedicated business systems with little sharing of information. The business systems themselves are not set up to do this and do not currently facilitate this.

5.7 Use of Spreadsheets

A significant problem in the UKCS oil and gas industry is the extensive use of personal spreadsheets to manage data and perform analyses from multiple data sources. This practice leads to the creation of information data islands, i.e. local storage of useful knowledge that is not visible to users of the company's IT systems. There is an increased risk of corrupted data leading to a reasonable mistrust of the data gathered.

Other issues with the use of personal spreadsheets are:

- Data is not managed (it usually entered by 'copying' from the CMMS user interface);
- There is no quality control; any trending performed may contain errors;
- Reports generated are not widely visible, resulting in valuable information collected that could be used as part of the decision making process being lost; and
- When engineers change roles, information is lost and it becomes reliant on the next individual in the role to find this information again.

5.8 Tag location issue

Tag location is an example of poorly recorded data that acting as a barrier to data trending. It has been found that the tag hierarchy identifying the location of equipment often does not include a separate tag for replacement equipment. The CMMS identifies a hierarchy based on functional location, e.g. company, location and system, but not the specific equipment items that make up that system. For example, if the system comprises a motor, gearbox and pump, all three items are covered by the same tag. If the pump is replaced, the new one is labelled with the same tag ID as the previous one, losing any traceability of the pump, associating it with a significant amount of maintenance and a large number of failures. This makes trending equipment to predict the next failure problematic.

A unique tag should be applied to each piece of equipment (a kit level tag) allowing tracking of where it has been, operating hours, failure history and type of failure etc.

5.9 Text analysis

A lack of appropriate mandatory fields within the typical CMMS has resulted in data being stored in plain text format. This text is rarely analysed because of the significant number of and inconsistent presentation of variables.

New advances in data analysis tools facilitate intelligent data mining from plain text fields allowing automated assessment. Examples of intelligent data mining and the results they can produce can be seen in Pool & Mason (2008). Improving the selection of mandatory fields in CMMS will aid data trending and analysis.

5.10 Trending, competence and reliability engineering

The offshore oil and gas industry does not generally employ significant numbers of trained and experienced engineers who understand reliability issues beyond entering data in to software tools. Suitably qualified/experienced engineers could be used to manage the data flow and to understand the results of the analysis and feed this into the ALE decision making process.

The wide application of fundamental reliability engineering in the industry would help to better identify equipment requirements and the means of measuring and analysing effectively actual performance, thereby improving equipment availability.

6. Data Trending Examples

The following two examples show how data trending can present useful knowledge to support ALE decision making.

6.1 Trending Example 1: percentage maintenance rework

Figure 3 depicts the percentage maintenance rework for a fictional installation. This lagging KPI of maintenance quality could include replacement part quality, technician work quality and/or technician competency.

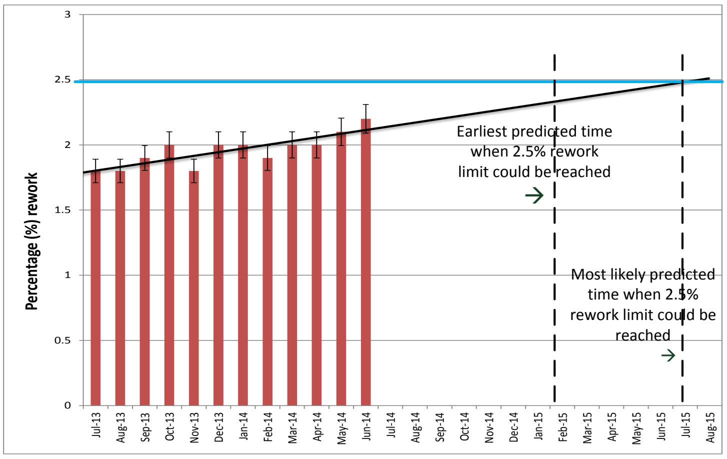

Figure 3: Graph showing trending applied to percentage of maintenance rework

Figure 3 shows a trend line fitted to fictional data covering an 11-month period representing a change in the percentage of maintenance tasks requiring rework on a monthly basis. The extrapolated line indicates future predictions based on the current trends that extends 12 months after the final recorded data.

If the maintenance rework limit was set at 2.5% of the total maintenance tasks performed per month, the linear trend fitted suggests that this limit could be met as early as February 2015, or as late as July 2015, representing a six month variation, which takes into account a standard deviation error which errs on the conservative side of the actual predicted data. The outcome of this initial trending analysis could be to instigate an investigation into the root cause of this apparent worsening trend before it results in significant maintenance performance issues. A worsening maintenance performance trend could indicate skill shortages of maintenance personnel, spare part obsolescence or asset degradation.

Discussions with industry professionals indicated that maintenance data are not often trended and so are not likely to be used to identify potential ALE issues, such as creeping change, obsolescence and asset degradation.

6.2 Trending Example 2: vessel wall thickness and corrosion rate trending

Non-Destructive Testing (NDT) is used to measure vessel and pipe wall thickness. It is not practical to measure the wall thickness of an entire vessel or pipe, so a sampling approach based on the corrosion TA's Risk Based Inspection (RBI) is often used.

This is a simulated example used to demonstrate the principle. In reality, measurements would be made at different points and treated statistically to gain the average wall thickness, the maximum depth of the corrosion pits etc. depending on the type of corrosion that would be expected in that vessel or pipe. These values could then be trended as described below.

In this analysis of simulated historical NDT vessel wall thickness data, a prediction is made of when the Minimum Allowable Wall Thickness (MAWT) would be reached, using linear trend analysis. Wall thickness measurements were taken at fixed locations for approximately six years, (Figure 4).

A linear trend analysis is applied to the data in Figure 4, showing an apparent constant rate of wall thickness deterioration from October 2004 until February 2008 for both test point 1 and test point 2, as depicted by trend lines T1 and T2 respectively.

A linear trend analysis is reapplied to the data measured starting February 2008 until January 2011 to account for a measured increase in the wall thickness deterioration rate. The date at which this change appears to occur, February 2008, is shown by a vertical dashed line labelled 'rate change' in Figure 4.

The new linear trend analysis shows an apparent increased but constant rate of wall thickness deterioration occurring from February 2008 until January 2011 for both test point 1 and test point 2, as depicted by trend lines T3 and T4 respectively.

Figure 4 shows that the vessel wall thickness measured at test point 2, reached the MAWT of 3mm, as depicted by the red line, by January 2011, as depicted by the vertical line P1.

Findings from this simulated case study are:

- According to the initial trend analysis, depicted by the trend line T2, the MAWT of 3mm was predicted to be reached approximately seven years later than measured result had the change in corrosion rate not occurred;
- The trend line predictions for test point 2, from T2 and T4, differ significantly, even though both trend lines appear to fit the data well for each period up to and after the rate change time;
- The simple trend analysis performed here has not accounted for vessel wall thickness at locations other than those measured;
- The new trend lines T3 and T4 were fitted to the measured data after the change in degradation rate was noticed; this could have occurred too late to prevent the MAWT limit being exceeded in real life, with potentially catastrophic consequences.

The change in the rate of wall thickness deterioration highlights problems in using a simple trend analysis for potentially complex problems such as corrosion.

Statistical methods can be used to model complex phenomena such as vessel corrosion to improve estimation of minimum wall thickness over large area, using sampling methods, when combined with reliability methods and system knowledge (HSE 2002). However, the use of statistics requires specialist knowledge to implement and interpret the results.

This example shows that trending can be used to predict asset degradation, if relevant pitfalls are taken into consideration, thus enabling long-term scheduling for repair or replacement of vessels and pipelines.

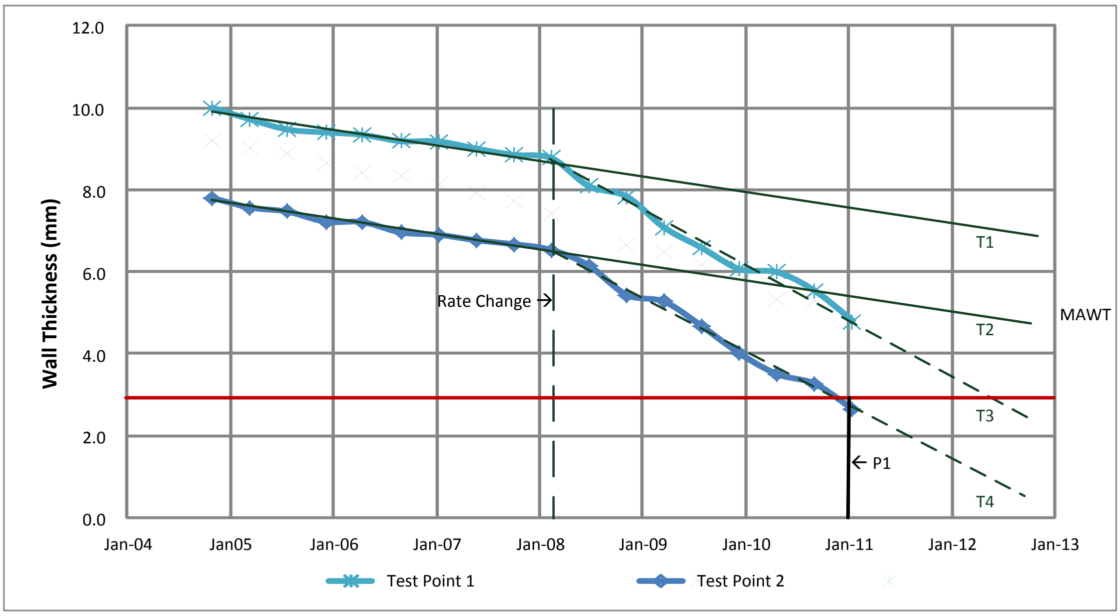

Figure 4: Simulated vessel wall thickness data trends including change in deterioration rate

7. Conclusions

It is concluded that the UKCS oil and gas industry records much useful information regarding the performance of their equipment, systems and maintenance processes, which could be used to support ALE decision making.

There are a number of barriers that have been identified as part of this work that could impede the industry's conversion of their stored data to useful knowledge to support ALE decision making. To make best use of this data, improvements would have to be made in the way that this information is typically stored, managed and utilised. For example, improved specification of the CMMS data storage fields would better facilitate consistent data recording and improve the usefulness of the stored data for all end users of these systems. Improved integration of company IT systems with the needs of the end user would be beneficial; e.g. a better interface between the company's reliability engineering function and IT department.

It is concluded that the UKCS oil and gas industry generally does not have leading KPIs that are designed to support ALE decision making. Careful consideration of ALE requirements and the application of data trending techniques that could transform existing lagging KPIs into leading KPIs would result in better informed ALE decision making.

This paper, having identified barriers that could impede the efficient use of existing data to support ALE decision making, has suggested areas for improvement including data storage, management and trending.

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